Assessment of lime stabilized slag- fly ash mixes as a highway material

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Assessment of lime stabilized slag- fly ash mixes as a highway material

Thesis submitted in partial fulfillment

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in

Civil Engineering

by

Baishnu Bhusan Behera

(Roll Number: 214CE1035)

based on research carried out

under the supervision of

Prof. Suresh Prasad Singh

May, 2017

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Prof. Suresh Prasad Singh

Professor

May 28, 2017

Supervisors' Certificate

This is to certify that the work presented in the thesis entitled *Assessment of lime stabilized slag- fly ash mixes as a highway material submitted* by *Baishnu Bhusan Behera*, bearing roll number 214CE1035, is a record of original research carried out by him under my supervision and guidance in partial fulfillment of the requirements of the degree of *Master of Technology* in *Civil Engineering*. Neither this thesis nor any part of it has been submitted earlier for any degree or diploma to any institute or university in India or abroad.

Prof. Suresh Prasad Singh

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Declaration of Originality

I, *Baishnu Bhusan Behera*, Roll Number *214CE1035* hereby declare that this thesis entitled *Assessment of lime stabilized slag- fly ash mixes as a highway material presents* my original work carried out as a post graduate student of NIT Rourkela and, to the best of my knowledge, contains no material previously published or written by another person, nor any material presented by me for the award of any degree or diploma of NIT Rourkela or any other institution. Any contribution made to this research by others, with whom I have worked at NIT Rourkela or elsewhere, is explicitly acknowledged in the dissertation. Works of other authors cited in this dissertation have been duly acknowledged under the sections "Reference".

I am fully aware that in case of any non-compliance detected in future, the Senate of NIT Rourkela may withdraw the degree awarded to me on the basis of the present dissertation.

May 28, 2017 *Baishnu Bhusan Behera*

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ABSTRACT

The objective of the thesis is to use industrial wastes rather than natural soil, aggregates, etc. in roads and highway construction after enhancing its strength, stability and durability. Conventionally, soil, stone aggregates, sand, bitumen, cement etc. are used in construction of roads and highway. Characteristic materials being limited in nature and thereby need of alternate materials is necessary. Gigantic quantities of soil are utilized as a part of the development of street and parkway yet adequate quantity of soil of required quality is not available effectively. To meet this demand extensive deforestation is being done which cause deforestation, soil disintegration and loss of rich soil which hampers in the farming efficiency. Additionally, cost of procurement of suitable quality of material is increasing. Worried about this, the researchers are searching for option materials for thruway development, and modern waste item is one such class. Stabilization method highlighted in this thesis is mainly to enhance the inherent strength of wastes like fly ash and crushed blast furnace slag (CBFS). This will automatically reduce the use of natural soil in addition to mitigate the disposal problems of industrial solid wastes in a great way. Fly ash and blast furnace slag was collected from Rourkela steel plant (RSP). Tests were conducted by blending fly ash and blast furnace slag in different proportions. The compaction characteristics, strength properties and the bearing value of different mixes are determined. From the compaction tests the optimum moisture content and the maximum dry density are determined for respective mixes. The strength parameters that are the unconfined compressive strength and CBR value for different mixes compacted to their respective MDD at OMC are evaluated. Further these mixes are blended with lime varying as 0%, 2%, 4%, and 8% and the UCS values are determined after a curing period of 0, 7 and 28 days. Similarly, the soaked CBR values of lime stabilized mixes at 0%, 2%, 4%, and 8% are determined after a curing period of 0 and 28 days. The effect of lime, curing period, fly ash and slag content with the unconfined compressive strength values and California bearing ratio values were studied. From the experimental study, it was observed that with addition of blast furnace slag to fly ash- slag mixes, the MDD increases and thereby decreases its OMC value linearly. It was also observed that the UCS value of the fly ash- slag mixes increases with the addition of slag up to slag content of 80% and there after the same decreases with further increases in slag content. The mix with 80% slag shows higher value as compared to 100% slag in the mix. Similar trend was observed for the CBR value for the fly ash- slag mixes, and it was seen that with increase with the slag content the CBR values also increases. However, for 100% slag the CBR shows a lesser value. Higher UCS and CBR values were reported at 8% lime content having a curing period of 28 days. The objective of the present study is to access the suitability of lime stabilized fly ash- blast furnace slag mixes as a highway construction material. So it is concluded that appropriate blending of fly ash with slag gives a better strength compared to individual materials. Further the desired strength required for different component of road can be achieved by stabilizing the mix with appropriate amount of lime.

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CHAPTER -1

INTRODUCTION

1. INTRODUCTION

1.1 INTRODUCTION

Conventionally road pavements are constructed using soil, aggregates and binder. Aggregates form major portion of the total volume of pavement structure and is the primary mineral material used in road construction. Large volumes of aggregates are consumed by the road building programme and similar quantities are used in maintenance works. It is estimated that construction of one cubic meter of Water Bound Macadam (WBM) involves use of about 1 .2 to 1 .4 cubic meter of aggregates, and laying of bituminous pavements involve even higher quantities. The aggregate extraction from natural rocks results into a lot of noise, dust, impacting vibrations, hazards, etc. Such ecological effects are creating worry in many parts of the nation. Unplanned exploitation of natural rock mass may sometimes lead to landslides of weak and steep hill slopes.

From the beginning of the industrial revolution the major issue in front of the industries is the disposal of the industrial waste. Industrial wastes are generally harmful to health and have environmental impact. Therefore, disposal of these wastes is a major issue in the current scenario. The solution to the above problem is to use these industrial waste to a maximum level for various purposes like road construction, highways and embankments. Moreover, by the use of these materials the environmental issues especially pollution can be reduced to a great extent.

In addition to aggregates and binder, tremendous amounts of soil are likewise required for development of roadway, highway and embankments Loss of valuable topsoil in this procedure renders the agricultural lands unfit for cultivation. Research and development studies ponders and fruitful field exhibit ventures have demonstrated that industrial waste like fly ash, iron and steel industry slags, rice husk, marble slurry dust, etc. can be used for roadway construction. While using such materials, the construction procedure would be broadly similar to construction of roads using conventional materials.

The fly ash used was collected from the Rourkela steel plant and blast furnace slag from the slag crusher unit of Rourkela steel plant. The geotechnical properties of fly ash and blast furnace slag were then evaluated by conducting various laboratory experiments. Specific gravity test was conducted for various fly ash- blast furnace slag mixes.

Modified Proctor test was also performed for evaluating the optimum moisture content (OMC) and maximum dry density (MDD) of fly ash- slag mixes. Lime stabilized samples were obtained for slag- fly ash mixes by enhancing the lime percentage (0%, 2%, 4%, and 8%). These stabilized samples were then subjected to unconfined compressive strength test following 0, 7 and 28 days of curing and California bearing ratio test for soaked and unsoaked conditions following 0 and 28 days of curing.

1.2 HISTORICAL BACKGROUND

Earlier, naturally available materials like soil, stone, sand and so on had been utilized for construction of roads. For instance, rocks, volcanic tuff and lime were utilized for the construction of Roman roads (Barth 1990). In this way, as the human advancement developed, some of the naturally available materials were processed further to derive new materials for instance, bitumen, concrete and so on. Moreover, due to excessive usage of these naturally occurring materials for building road and other infrastructures, these have started depleting gradually. At the meantime, large amount of industrial and domestic wastes is creating serious environmental problems. In this connection, road researches have been trying to find out possible ways to use some of the waste as alternative materials for road construction. From there the concept of Fly ash, Pond ash, Waste glass, Construction and Demolition waste, Colliery spoil, Blast furnace slag as a bulk filling material in pavement layers can be said to have opened up since then.

1.3 AN OVERVIEW OF FLY ASH AND BLAST FURNACE SLAG PRODUCTION AND ITS UTILISATION

Fly Ash, an industrial by-product from Thermal Power Plants (TPPs), with current annual generation of approximately 205 million tones. Cement and concrete industry accounts for half the fly ash utilization. The other areas are low lying area fill, roads and embankment, dike raising, brick manufacturing and safe disposal of fly ash in paint industry, agriculture, etc.

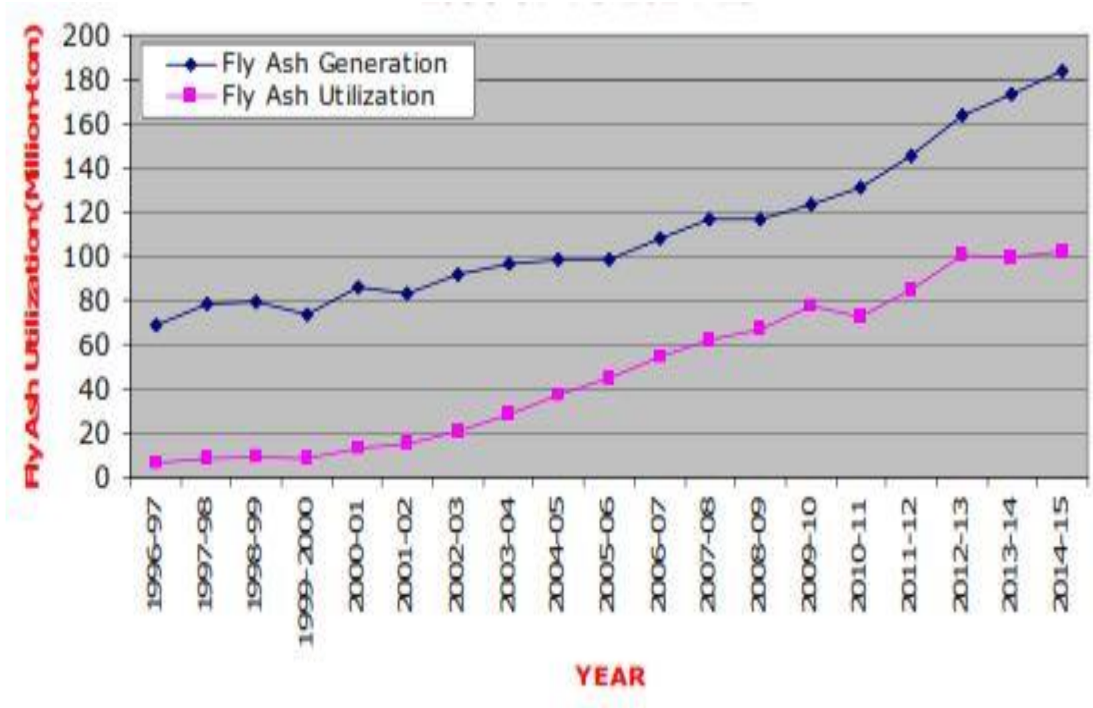

Figure 1.1 Generation and utilization on fly ash in India
(Source: Central Electricity Authority, New Delhi, 2015)

Despite the continuous efforts to increase the utilization rate, the government still does not achieve maximum utilization. Considering the future aspect there will be certainly increase in the thermal power plant in the country, hence it is predicted that the fly ash generation will also increase and achieve the highest level of ash utilization.

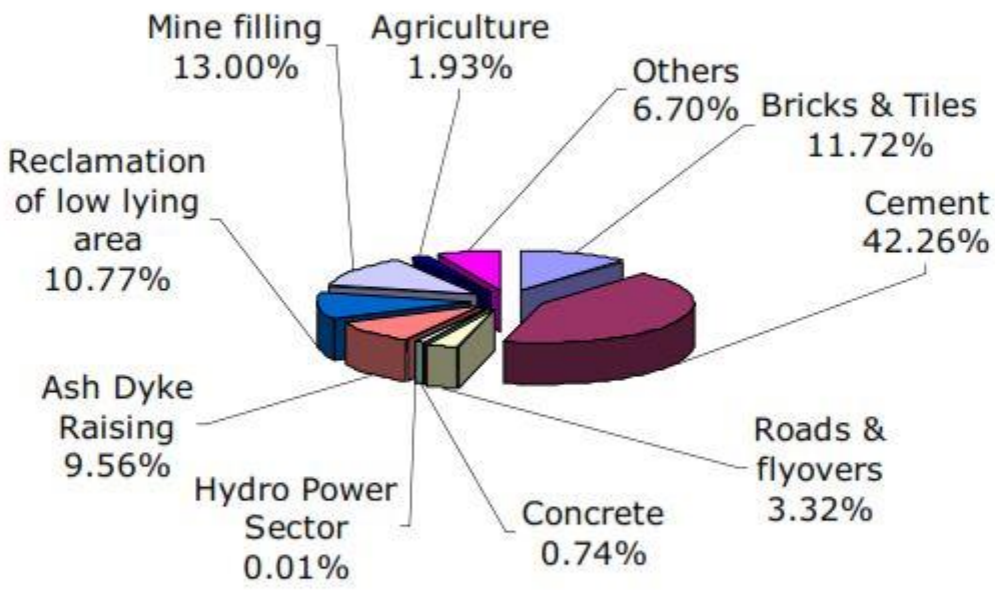

Figure 1.2 Modes of fly ash utilization
(Source: Central Electricity Authority, New Delhi, 2015)

Table 1.1 Economic Benefits of Fly ash
(Source: Central Electricity Authority, New Delhi, 2015)

Sl.No.	Utilization	Fly ash consumption(millions tones /year)	Savings per year(rupees in crores)
1	Cement	25	2500
2	Road embankment	15-20	100
3	Mine fills	15-20	150
4	Bricks	5	20
5	Agriculture	200	3000

Total- 5770

The slag produced in the blast furnace during pig iron manufacturing is known as blast furnace slag and the slag produced at steel melting shop is the steel slag. The quantity of slag manufactured mainly depends on the raw materials and type of furnace used. The data concerning plant wise capacity of iron and steel slag in the country is given in Table 1.2

Table 1.2 Plant wise capacity of iron and steel slag in India.
(Source: Indian Minerals Yearbook, 2015)

Steel Plant	Capacity for granulation('000 tpy)
Bhillai Steel Plant, Durg, Chattisgarh	2675
Bokara Steel Plant, Bokara, Jharkhand	7884
Rourkela Steel Plant, Rourkela, Odisha	600
Durgapur Steel Plant, Durgapur, West Bengal	566
IISCO Steel Plant, Burnpur, West Bengal	400
Visvesvarya Iron & Steel Plant, Bhadravati, Karnataka	400
Rastriya Ispat Nigam Ltd., Vishakhapatnam, Andhra Pradesh	440
IDCO Kalinga Iron Works Ltd., Barbil, Odisha	53
JSW Steel Ltd., Bellary, Karnataka	-
Tata Steel Ltd., Jamsedpur, Jharkhand	2100
Visa Steel Ltd., Kalinganagar, Odisha	175

Neelachal Ispat Nigam Ltd.,Kalinganagar, Odisha	-
Sona Alloys Private Ltd., Satara, Maharashtra	100.8

1.4 ORAGANISATION OF THE THESIS

The work presented in this thesis comprises essential information of various properties of fly ash, blast furnace slag and lime. The observations made in literature part and experimental procedure are according to the Indian Standard. The outline of this thesis is presented in Figure 1.3. It comprises of 6 chapters and the detail description is given below.

Chapter 1 of this thesis introduces some basic facts on the significance of fly ash and blast furnace slag production and its utilization, and also the economic benefits of fly ash. Also deals with a brief description historical background of fly ash and blast furnace slag.

A critical review of relevant literature is given in Chapter 2. This includes microstructural, chemical, mineralogical analysis of fly ash as a pavement material. The effects of lime, curing period and fly ash/slag content are also reviewed in this chapter.

Chapter 3 of this thesis deals with the experimental methodology, details of the experimental performed.

Chapter 4 of this thesis deals with test results and discussion of various fly ash- blast furnace slag mixes. The grain size distribution curve and compaction characteristics were studied. The effect of lime, fly ash content, slag content with respect to UCS and CBR values are investigated.

Chapter 5 of this thesis gives the detailed summary and conclusion of the work.

Chapter 6 of this thesis gives the list on the references used in the study.

1.5 STRUCTURE OF THE THESIS

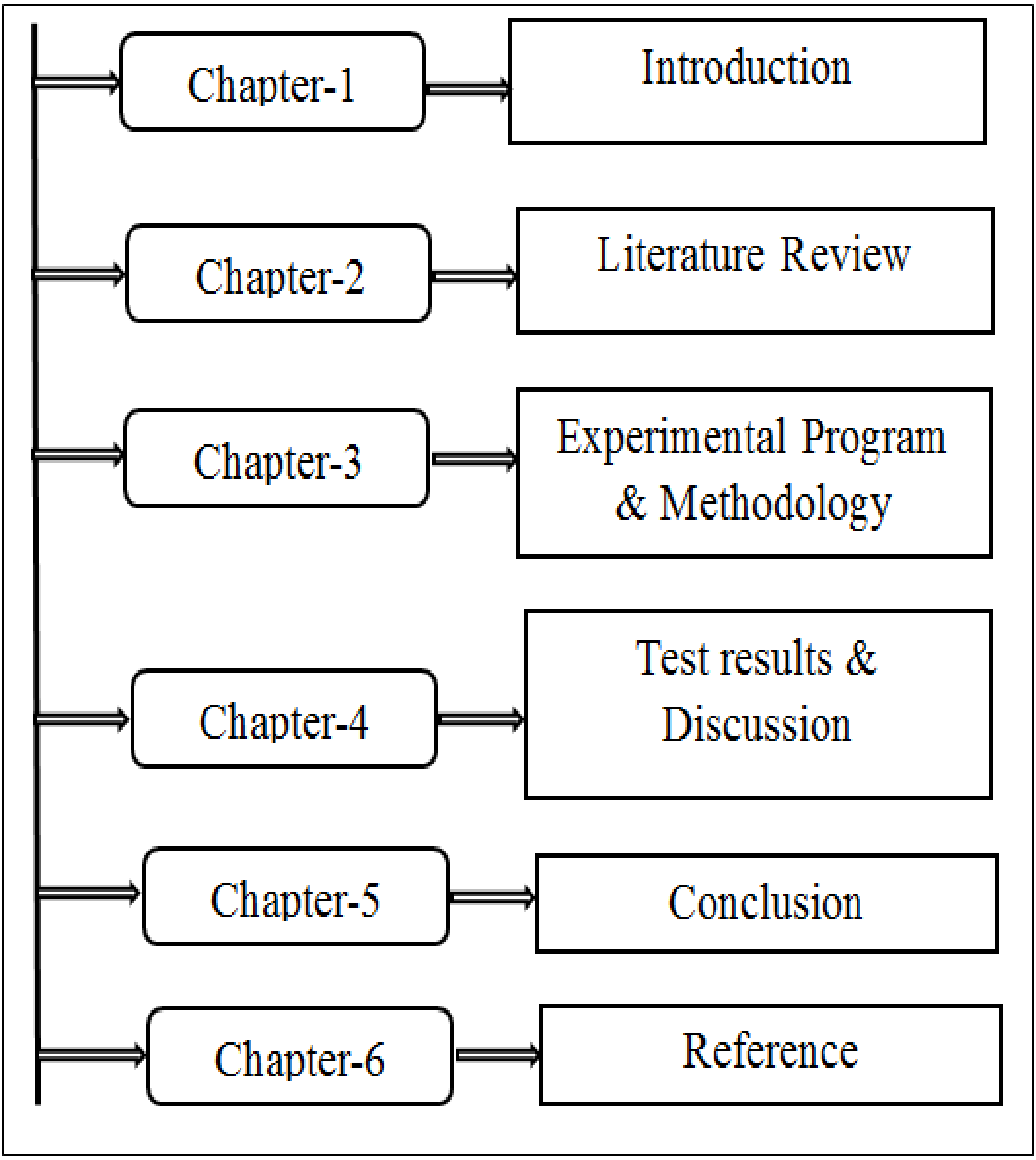

Figure 1.3 Structure of the thesis

CHAPTER 2

LITERATURE REVIEW

2. LITERATURE REVIEW

2.1 INTRODUCTION

Fly ash is a byproduct generated from the thermal power plants. The main issue with fly ash is its disposal which possesses huge economic loss to the power plants. Thus, a special consideration is required for the utilization of fly ash in highway, embankment constructions as a replacement to conventional natural materials. Blast furnace slag is formed as a co product in the process of iron production. The utilization of blast furnace slag in geotechnical constructions needs a study. Lime is produced by calcination of limestone in a lime kiln at temperatures above 1000°C

2.2 AN OVERVIEW OF A PAVEMENT LAYER

The various layers in a pavement generally consist of sub grade, sub base course, base course, and surface course. The sub grade consists of existing soil, which should be clean and free from organic matter. Moreover, the CBR value should not be less than 25%. The sub base course layer is made up of granular material and is an optional layer if the sub grade is of good quality. The CBR value for this layer lies between 20-30%. The base course lies just below the wearing course, hence quality of the material used should be highlighted. The CBR values of this layer lies between 80-100 %. However, depending upon the expected traffic the strength of these layers may vary.

Figure 2.1 Different pavement layers

2.3 INDUSTRIAL WASTE PRODUCTS: AN OVERVIEW

2.3.1 General

Since the beginning of industrial revolution industrial waste plays a vital role. The industrial waste can effectively replace soil, stone aggregate which are non- replenishing source. Table 2.1 shows the possible usage of industrial waste products in highway construction.

Table 2.1 Possible usage of industrial waste products in highway construction

SL.NO.	WASTE PRODUCT	SOURCE	POSSIBLE USAGE
1	Fly ash	Thermal power station	Bulk fill, filler in bituminous mix
2	Blast furnace slag	Steel industry	Base/ Sub-base material, Binder in soil stabilization
3	Construction and demolition waste	Construction industry	Base/ Sub-base material, bulk-fill, recycling
4	Spent oil shale	Petrochemical industry	Bulk-fill
5	Cement kiln dust	Cement industry	Stabilization of base, binder in bituminous mix
6	Marble dust	Marble industry	Filler in bituminous mix

2.3.2 Fly Ash: An Overview

Fly ash is the usually the by-product of thermal power plants, and generally is supposed to be a waste material and the major problem from environmental point of view is its disposal point of view, which moreover requires a huge area for disposal. Thermal power plants generally produce three types of ashes fly ash, pond ash and bottom ash.

Fly ash is a fine structured and mainly consists of silica, alumina and iron. Fly ash when mixed with lime and water forms a cementitious compound. With this unique property fly ash can be used as a replacement to cement in various fields.

According to ASTM C 618 (AASHTO M 295) Class F and Class C fly ashes are commonly used as pozzolanic admixtures. Class F fly ash are having low-calcium within 10% with carbon contents usually less than 5%, but some may be as high as 10%. Class C materials are often high-calcium between 10-30% with carbon contents less than 2%. Fly ash has a scope to be used in roadway constructions, including pavement structural layers such as base/ sub- base layers to have longer lasting and sustainable infrastructure.

2.3.2.1 Fly Ash for Road Construction

In the present scenario to meet the demand of electricity a large number of thermal power plants have been set up in our country. Presently around 205 million tons of fly ash is produced per annum. The major issue on the production of fly ash is that its environmental issues which creates health hazards and requires large areas for its disposal. Thus major challenge is to use this fly ash for roadway construction.

2.3.2.2 Design and Construction of Fly Ash Embankments

The design of fly ash embankments is similar to design ot soil embankments. Fly ash embankments of height up to 3 m can be constructed adopting a side slope of 1:1.5 (V:H). A flatter slope of 1:2 may be adopted at places where weak subsoil conditions exist or the embankment is constructed in flood prone areas. Regardless of the height of the embankment, fly ash embankments should always be constructed with soil cover. For construction of embankments of height more than 3 m, the design process for embankments involves the following steps:

- Site investigations
- Characterization of materials
- Detailed design

In case of high embankment construction, the site investigations are carried out as per IRC:75. The design of embankment is an iterative process. It involves developing conceptual plans, which satisfy site needs, design requirements pertaining to slope stability, bearing capacity, settlement and drainage.

2.3.2.3 Factors affecting properties of fly ash

The various properties of fly ash are a function of several variables.

(1) Source of the coal used.
(2) Degree of pulverization of the coal.
(3) Boiler unit design.
(4) Loading and firing condition.
(5) Various storage and handling process.

2.3.2.4 Environmental Impact of Fly ash

The environmental impact of the fly ash can be listed below.

- Due to the construction of large ash disposal areas there is a huge loss of agricultural production, land for grazing, habitat. Moreover, the design of these areas is inefficient in terms of economy.
- Due to the disposal of fly ash water sources are also get polluted. The pollution of the ground water occurs mainly through contamination of groundwater from leachate and of surface water from discharge of fly ash effluent.
- The emission of dust from the fly ash also leads to air pollution.
- Failure of the earthen dam causes a threat to life.

2.3.2.5 Problem Using Fly ash

Fly ash generally shows minimum strength under saturated condition. Moreover, the shear strength parameters, unit cohesion and angle of internal friction depends on aging and degree of saturation.

2.3.2.6 Uses of Fly ash

Fly ash can be used for numerous applications. Some of the application areas are the following:

- In land fill and as structural fill in retrieving low areas.
- In the manufacture of cement.
- For stabilizing the soil in various pavement layers.
- For brick manufacturing.
- As a replacement in mortar and concrete.

2.3.3 Blast Furnace Slag (BFS): An Overview

Blast furnace slag (BFS) is formed as a co- product in the process of iron production. It primarily consists of silicates, alumino-silicates, and calcium-alumina-silicates. Figure 2.2 presents a schematic diagram, which shows the process of production of blast furnace slag.

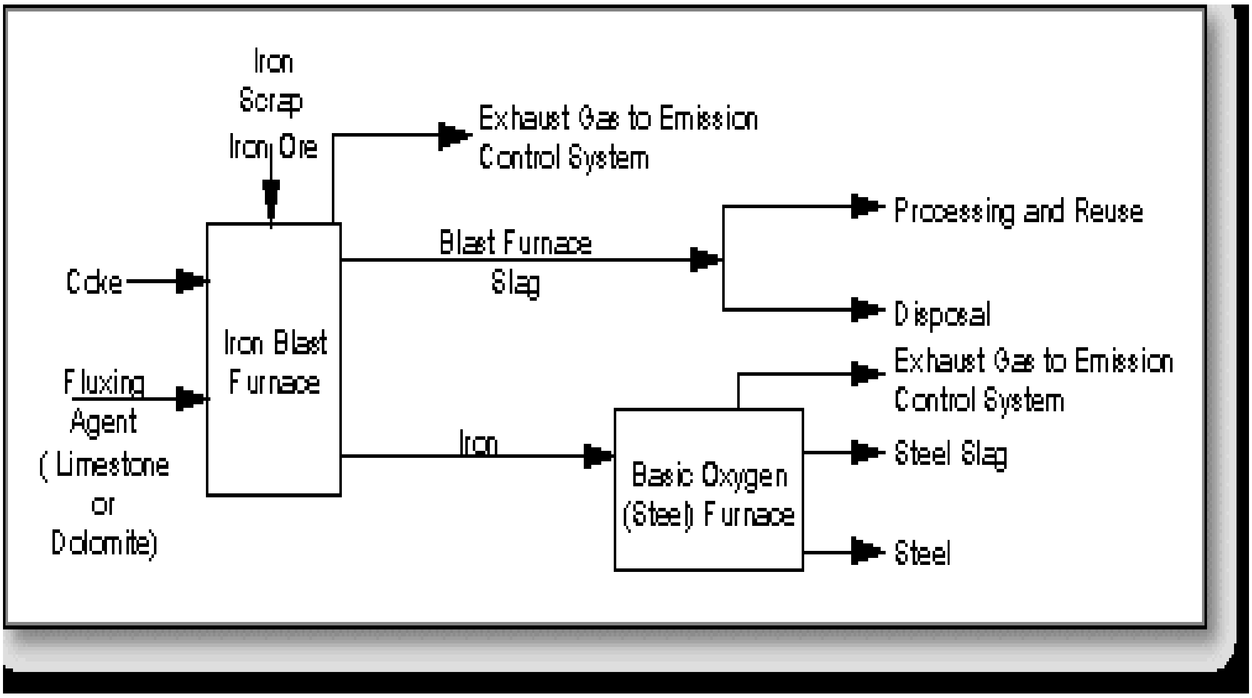

Figure 2.2 Schematic diagram of production of BFS.

2.3.3.1 Chemical and Mineralogical Composition of Blast Furnace Slag

The chemical composition of the blast furnace slag is presented in Table 2.2

Table 2.2 Major Chemical Constituents in Blast Furnace Slag

Constituent	**Weight Percentage**
Lime (CaO)	32 to 45
Magnesia (MgO)	5 to 15
Silica ($Si0_2$)	32 to 42
Alumina(Al_20_3)	7 to 16
Sulphur (S)	1 to 2
Iron Oxide (Fe_20_3)	0.1 to 1.5
Manganese Oxide (MnO)	0.2 to 1

Table 2.3 Minerals Constituents of air-cooled Blast Furnace Slag

Mineral	**Formula**
Akermanite	$2CaO\text{-}MgO\text{-}2SiO_2$
Gehlenite	$2CaO\text{-}Al_20_3\text{-}SiO_2$
Wollastonite	$CaO\text{-}SiO_2$

Dicalcium silicate	$2CaO-SiO_2$
Merwinite	$3CaO-Mgo-2SiO_2$
Anorthite	$CaO-Al_2O_3-2SiO_2$
Monticellite	$CaO-MgO-SiO_2$

2.3.3.2 Factors affecting properties of Blast Furnace Slag

The chemical and physical composition of a blast furnace slag is a function of numerous variables.

(1) Composition of iron ores.
(2) Composition of available flux stones and fuels.
(3) Proportions required for efficient furnace operations.

2.3.3.3 Uses of Blast Furnace Slag

Some of the relevant application areas are as follows:

- In road base and in structural fill.
- As railroad ballast.
- Primarily used in base courses, with trace amounts used in base stabilized with cement or lime-fly ash mixes.
- As aggregate in asphalt concrete.

2.3.4 Lime: An Overview

Lime in form of calcium oxide (CaO), commonly known as quicklime, is a white, caustic and alkaline crystalline solid at room temperature. Lime also contains magnesium oxide, silicon oxide and smaller amounts of aluminum oxide and iron oxide.

2.3.4.1 Production of Lime

Lime is produced by calcination of limestone in a lime kiln at temperatures above 1000°C. First of all, calcium carbonate ($CaCO_3$) is converted into calcium oxide (CaO) and carbon dioxide (CO_2). Active calcium oxide is highly reactive.

2.3.4.2 Different forms of Lime and usage

The various forms of lime which include quicklime, hydrated lime or lime slurry can be utilized to treat the soil. Quicklime is manufactured chemically from calcium carbonate to form calcium oxide. Hydrated lime is generally formed when quicklime chemically reacts with water.

Lime can be used to treat a range of soil types which can be used alone or in combination with other materials. The mineralogical properties of the soils will determine their degree of reactivity with lime and the ultimate strength that the stabilized layers will develop.

2.3.4.3 Uses of Lime

Some of the relevant application areas are as follows:

- In soil stabilization for road, earthen dams. It is supplementary to low quality soils to yield a working base and sub-base.
- Primary ingredient in masonry mortars.
- Used to treat soils in order to develop their workability and load - bearing characteristics.
- Excellent choice for short term modification of soil properties includes reduction in plasticity, moisture holding capacity and improved stability.

2.4 ENGINEERING PROPERTIES ON COMPACTED/STABILIZED FLY ASH

Lav (2000) carried out an analysis considering the microstructural, chemical, mineralogical, and thermal properties of fly ash, to use as a pavement base material. For this work the fly ash was stabilized separately for cement and lime. The effects of lime and cement stabilization were studied. The results obtained from the lime and cement stabilized samples showed that for both types of stabilizing agents the hydration products are same that accounts for strength gain.

Pandian and Krishna (2002) made a study on the CBR behavior of cement stabilized soil fly ash mixes and obtained the suitability for use as road sub-base. The CBRs corresponding to the two optimum levels are 24.7% and 33% after 28 days of curing with 3% cement, which was significant for field application. A minimum CBR of 20% was recommended for use in the sub base layer for road pavement. Hence in the present work the cement content has been restricted to 3%.

Fernandez et al. (2004) conducted a microscopic study on a set of fly ash samples which are activated by an alkali and thermally cured. The morphology of fly ash particles was studied that can be applied to physical life situation. The fly ash was thoroughly mixed with alkaline activators and the paste was allowed to solidify by curing. The results show that with time the degree of reaction is increasing continuously.

Lav et al. (2005) studied on the utilization of class F fly ash as a base material in road pavements. In this work only aggregate, fly ash and cement were used as the main motive is to use the waste material. In this study, cement content was varied (2%, 4%, 8%, 10%) to prepare samples. The test results obtained from the tests were then incorporated into pavement study.

Ghosh and Subbarao (2006) investigated the suitability of lime/gypsum stabilized fly ash as a roadway material. In this study unconfined compressive strength, bearing ratio, tensile strength and slake durability test were conducted. The effect of lime content, gypsum content and curing period on the above characteristics was highlighted. From this study, it can be said that stabilized class F fly ash has a potential for providing a strong road base.

Bera et al. (2008) carried out unconfined compressive strength test on both unreinforced fly ash and reinforced fly ash with jute geotextiles. The effect of degree of saturation, size of the sample, number of jute geotextile layers and age of the sample on UCS has been investigated.

Nassarr et al. (2013) studied the effect of high volume fly ash on pavement construction. From the study it was found that the fly ash in pavement can be used as partial replacement for cement due to enhanced durability characteristic.

Pal and Rajak (2015) investigated the CBR values of soil mixed with fly ash and lime in different percentages. Soil was mixed with lime at 5%, 8%, 10% and 12% and with fly ash at 10%, 20%, 30% and 40% to enhance its CBR values. The optimum moisture content increases and dry density decreases with increase in fly ash and lime percentage due to the variation in clay and silt size particle. Addition of fly ash and lime enhanced the Unsoaked CBR value of the soil.

2.5 ENGINEERING PROPERTIES ON COMPACTED/STABILIZED SLAG

Wild et al. (1998) focused on the use of granulated ground blast furnace slag for highway and other different foundation layers by evaluating the beneficial effect on strength by substituting GGBS for lime in lime-stabilized clay soils, particularly in the presence of gypsum. The result shows that there is improvement in strength by the addition of lime with GGBS and the content of lime and slag is to be maintained for required bearing capacity and strength.

Behiry (2012) evaluated the effect of quality of steel slag on mechanical properties of mixes with crushed limestone aggregates, which was used as sub base material. The results show that by increasing the steel slag percentage to the limestone in the blended mix increases the mechanical properties such as maximum dry density, California Bearing Ratio and resilient modulus. The best density and strength for the layer with the least construction costs obtained at a blended mix of 70% steel slag percentage to 30% limestone.

Bhattacharyya (2012) made a study on use of Blast Furnace Slag in sub base/base layer of pavement. Test was conducted for suitability of slag in pavement layers. Various field studies of BFS layers after laying and after compaction were made analyzed. From the analysis it was obtained that cumulative % retained decreases. It was concluded that the material was very useful alternative of stone material in GSB layer.

Sinha et al. (2013) focused on the geotechnical characteristics of slag design. The stability analysis of embankment, sub-grade and sub base layers and suitability of slag in bituminous layers were highlighted. In this study the utilization of slag in different layer of roads was carried out. From the study it was observed that slag can be used for embankment construction and for sub grade, but not suitable for bituminous layers.

Yadu and Tripathi (2013) focused on the effectiveness of granulated blast furnace slag in improving the engineering behavior of soft soil(CI-MI). Different proportions of GBS such as 3%,6%,9% and 12%was combined with the soil and CBR as well as UCS test was conducted and it was obtained that 9% GBS is optimum for improving strength.

2.6 ENGINEERING PROPERTIES OF COMPACTED/STABILIZED FLY ASH- SLAG MIXES

Puertas et al. (2000) carried out a study on activation of fly ash / slag pastes with NaOH solution. The effect of curing temperature, activator concentration and fly ash slag ratios were studied. From the study it was observed that with increase in slag content, the compressive strength also increases. Moreover, the curing temperature has a positive trend at initial days, and at longer days the effect is reversed. It was observed that at a curing temperature of 25°C the strength attained was higher.

Singh and Ramaswamy (2005) conducted a study to assess the suitability of cement stabilized fly ash- granulated blast furnace slag(GBFS) mixes for its use as embankment, base and sub- base courses of highway pavement. The compaction characteristics, unconfined compressive strength and CBR value of the stabilized fly ash- GBFS mixes were evaluated . In the study cement content was varied from 0 to 8 percent at 2 % interval, whereas slag content was varied from 0 to 10, 20, 30 and 40 % respectively. From the compaction test it was studied that the mixes show an increase in MDD. Moreover, the UCS and CBR values of compacted mixes depend, to a large extent, on the cement content.

Shen et al. (2009) evaluated the properties of steel slag, fly ash and phosphogypsum for utilization as a road base material. The strength characteristics, resilience modulus and splitting strength were studied. It was observed that the early strength was higher than that of lime- fly ash and lime- soil mixes and also the long term strength was much higher than the cement stabilized materials. Thus it has a potential to be a good road base material.

Singh et al. (2008) studied on cement stabilized fly ash–(GBFS) mixes for suitability in road embankments and in pavement layers. For this study compaction test, unconfined compressive strength (UCS) test and California Bearing Ratio (CBR) test were conducted by varying the cement content and slag content. The test results shows that with increase in cement and slag content the MDD of the mixes increases and OMC decreases. Similarly the CBR values were also on increasing trend with addition of cement and slag. Thus, the mixes can suitably use in base and sub- base courses.

Deb et al. (2014) studied the effect on the strength development of geopolymer with the addition of ground granulated blast-furnace slag (GGBFS) with class F fly- ash when cured in ambient temperature. Here, GGBFS was mixed in increasing percentage of 0%, 10% and 20% of the total binder with variable activator content of 35 and 40%. From the study, it was seen that there is increase in strength and decrease in workability with higher GGBFS values.

Gao et al. (2015) investigated the effects of the raw materials on the workability, setting times, reaction kinetics, gel characteristics and compressive strength of cured alkali activated slag, fly ash and limestone mixes. From the study it was observed that slump flow increases with fly ash content and the setting time was reduced with increase in slag content.

Sharma and Sivapullaiah (2016) investigated the effect of the joint activation of fly ash, and ground granulated blast-furnace slag, on the unconfined compressive strength of mixtures of the two materials. The strength was found to increase with slag content. However, the specimens consisting of 30 and 40% of slag and cured for 28 d showed higher strength than the individual materials. Moreover, the effect of different percentages of lime on the strength of the fly ash–slag mixtures was investigated. Tremendous increase in strength was observed with the addition of even 2% of lime. This study suggests that properly designed combinations of fly ash–slag–lime can be used as construction materials for infrastructure projects such as structural fills or subgrade and sub-base courses in pavements without requiring large quantities of lime.

2.7 PROBLEM STATEMENT

The motive of the thesis is to utilize the industrial wastes like slag and fly ash instead of natural soil and aggregates for the highway construction after stabilizing the slag- fly ash mixes with lime.

2.8 OBJECTIVE OF THE WORK

Accessing the suitability of lime stabilized fly ash- blast furnace slag mixes as a highway construction material.

2.9 SCOPE OF THE WORK

- Characterization of raw materials.
- Study on the compaction characteristics of the slag- fly ash mixes.
- Determination of unconfined compressive strength of the slag- fly ash mixes stabilized with various percentage of lime and cured for 0, 7, 28 days.
- Determination of California Bearing Ratio test of the lime stabilized slag- fly ash mixes for Soaked and Unsoaked Condition at 0 and 28 days of curing.
- Accessing the suitability of above stabilized mixtures for different components of pavement.

CHAPTER 3

EXPERIMENTAL PROGRAMME AND METHODOLOGY

3. EXPERIMENTAL PROGRAMME AND METHODOLOGY

3.1 INTRODUCTION

The major issue of thermal power plants is safe and economic disposal of fly ash. Hence, utilization of this fly ash in geotechnical constructions will reduce the burden of the thermal power plants. Thus the pavement to be constructed using fly ash should be assessed in terms of safety and stability. The industrial waste fly ash and blast furnace slag was collected from Rourkela steel plant. Specific gravity, grain size distribution, compaction characteristics was performed for various fly ash- slag mixes. Lime stabilized samples of slag- fly ash mixes were prepared at an increasing percentage of 0%, 2%, 4% and 8%.Unconfined compressive strength was performed for the lime stabilized fly ash- slag mixes after 0, 7 and 28 days of curing. Similarly, California bearing ratio test was conducted for soaked and unsoaked conditions after 0 and 28 days of curing. Details of the materials used, sample preparation and testing procedure adopted have been outlined in this chapter.

3.2 MATERIALS USED

3.2.1 Fly Ash

3.2.1.1 Source of Fly ash

Fly ash used in this study was collected from the Rourkela steel plant. Fly ash samples were dried at a temperature of around 105-110^{o}c. In order to separate the vegetative matter or some foreign matter, the fly ash was screened through 2 mm sieve and then mixed thoroughly to bring homogeneity.

3.2.1.2 Physical Properties of Fly ash

The physical properties of fly ash were evaluated and presented in Table 3.1.

Table 3.1 Physical properties of Fly ash

Properties	**Value**
Colour	Light grey
Specific gravity, G	2.44
Maximum dry density (gm/cc)	1.36
OMC (%)	32.4
Shape	Rounded/sub-rounded

Uniformity coefficient, (Cu)	7.755
Coefficient of curvature, (Cc)	1.939
Plasticity Index	Non-plastic

3.2.2 Blast Furnace Slag (BFS)

3.2.2.1 Source of Blast furnace slag

The blast furnace slag was collected from the slag crusher unit of Rourkela steel plant. The finer portion of the crusher unit that is portion passing through the 20mm sieve was collected and is mixed thoroughly in order to bring homogeneity to the sample. The material was first sun dried followed by drying in a hot air oven at a temperature of 105-110^{o}C. The dried material is stored in containers for further use.

3.2.2.2 Physical Properties of Blast furnace slag

The physical properties of Blast furnace slag were determined and presented in Table 3.2.

Table 3.2 Physical properties of Blast furnace slag

Properties	**Value**
Colour	Brown
Specific gravity, G	3.10
Maximum dry density (gm/cc)	2.58
OMC (%)	8.96
Shape	Sub-rounded /Angular
Uniformity coefficient, (Cu)	30.625
Coefficient of curvature, (Cc)	0.816
Plasticity Index	Non-plastic

3.2.3 Lime

3.2.3.1 Source of Lime

Lime used in the study is a form of calcium hydroxide ($Ca(OH)_2$),95 % extra pure, was taken from the market and was kept in air tight bags.

3.3 DETERMINATION OF INDEX PROPERTIES

3.3.1 Determination of Specific gravity

The specific gravity of fly ash and slag was determined according to IS: 2720 (Part-III, Section –I/II) 1980. The specific gravity of fly ash and slag was found to be 2.44 and 3.10 respectively.

3.3.2 Determination of Grain Size Distribution

For determination of grain size distribution, sieve analysis was conducted for coarser particles as per IS: 2720 part (IV), 1975 and also hydrometer analysis was conducted for finer particles as per IS: 2720 part (IV). Coefficient of uniformity (Cu) and coefficient of curvature (Cc) for fly ash was found to be 7.755 and 1.939 respectively. The grain size distribution curve of fly ash is presented in Figure. 3.1. Similarly, for determination of grain size distribution of blast furnace slag, it was passed through test sieve 20 mm down. Sieve analysis was conducted for coarser particles as per IS: 2720 part (IV),1975. Coefficient of uniformity (Cu) and coefficient of curvature (Cc) for blast furnace slag was found to be 30.625 and 0.816 respectively. The grain size distribution curve of blast furnace slag is presented in Figure. 3.2. Combined graphs for various slag- fly ash mixes were plotted and presented in Figure. 3.3.

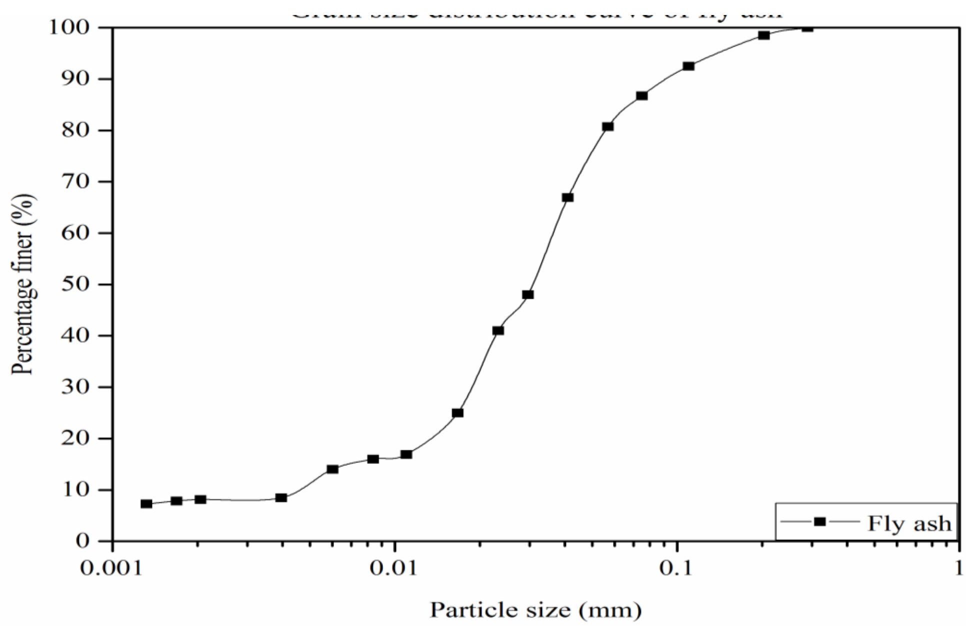

Figure 3.1 Grain Size Distribution Curve for Fly Ash

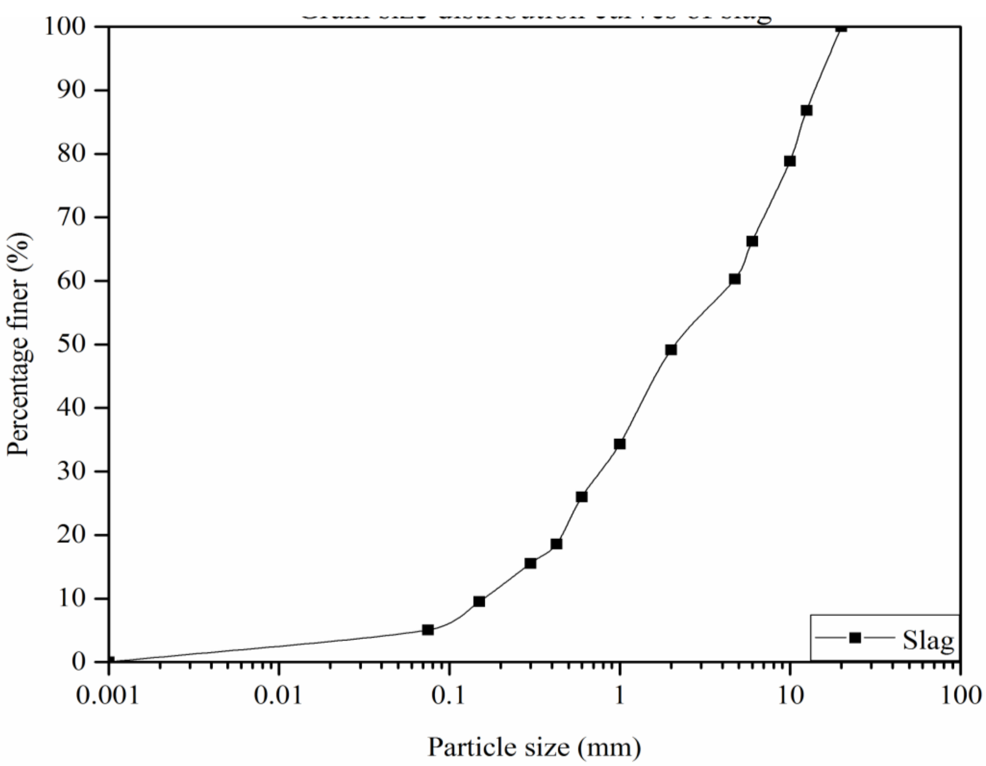

Figure 3.2 Grain Size Distribution Curve for Blast Furnace Slag

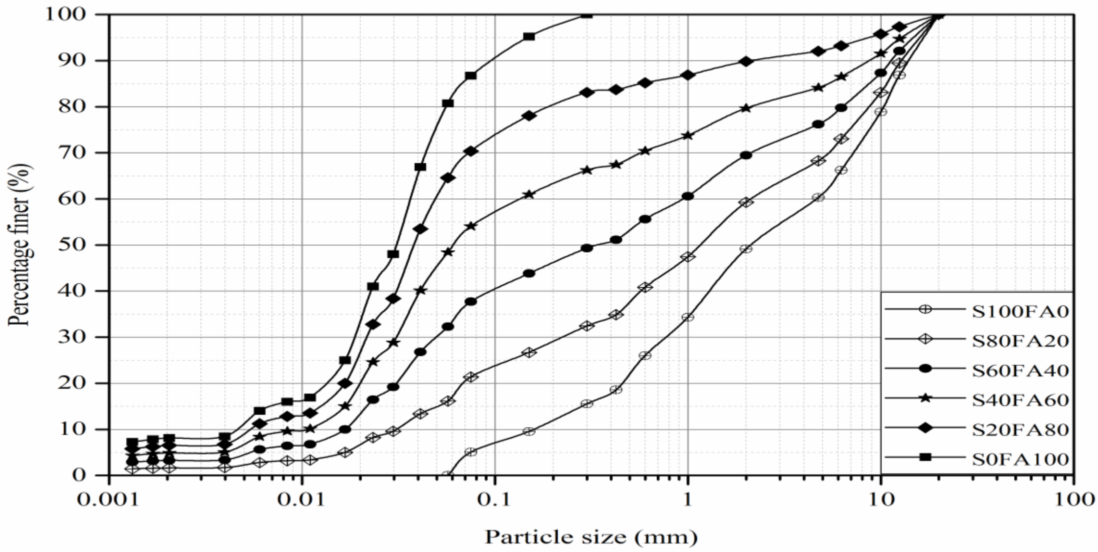

Figure 3.3 Grain Size Distribution Curve for Fly ash – Slag mixes

3.4 DETERMINATION OF ENGINEERING PROPERTIES

3.4.1 Compaction Characteristics

The compaction characteristics were found by using compaction tests as per IS: 2720(Part -8)-1983. For this test, slag- fly ash mixes was mixed properly with requisite amount of water and then the mix was compacted in proctor mould in five equivalent layers using rammer of 4.5 kg. The moisture content of the compacted mixture was determined as per IS: 2720 (Part-2) 1973.From the compaction characteristics, optimum moisture content (OMC) and maximum dry density (MDD) were determined. The test results are presented in Table 3.3. The compaction graph of the various slag- fly ash mixes are shown in Figure.

Table 3.3 Compaction characteristics of fly ash – blast furnace slag mixes

Sl.No.	% Fly Ash	% Slag	MDD(kN/m^3)	OMC
1	100	0	13.342	32.4
2	90	10	13.636	31
3	80	20	13.911	28.2
4	70	30	15.206	25
5	60	40	16.187	21.8
6	50	50	17.462	18.2
7	40	60	18.639	16.2
8	30	70	20.601	13.8
9	20	80	21.925	10.8
10	10	90	22.749	10
11	0	100	25.309	8.96

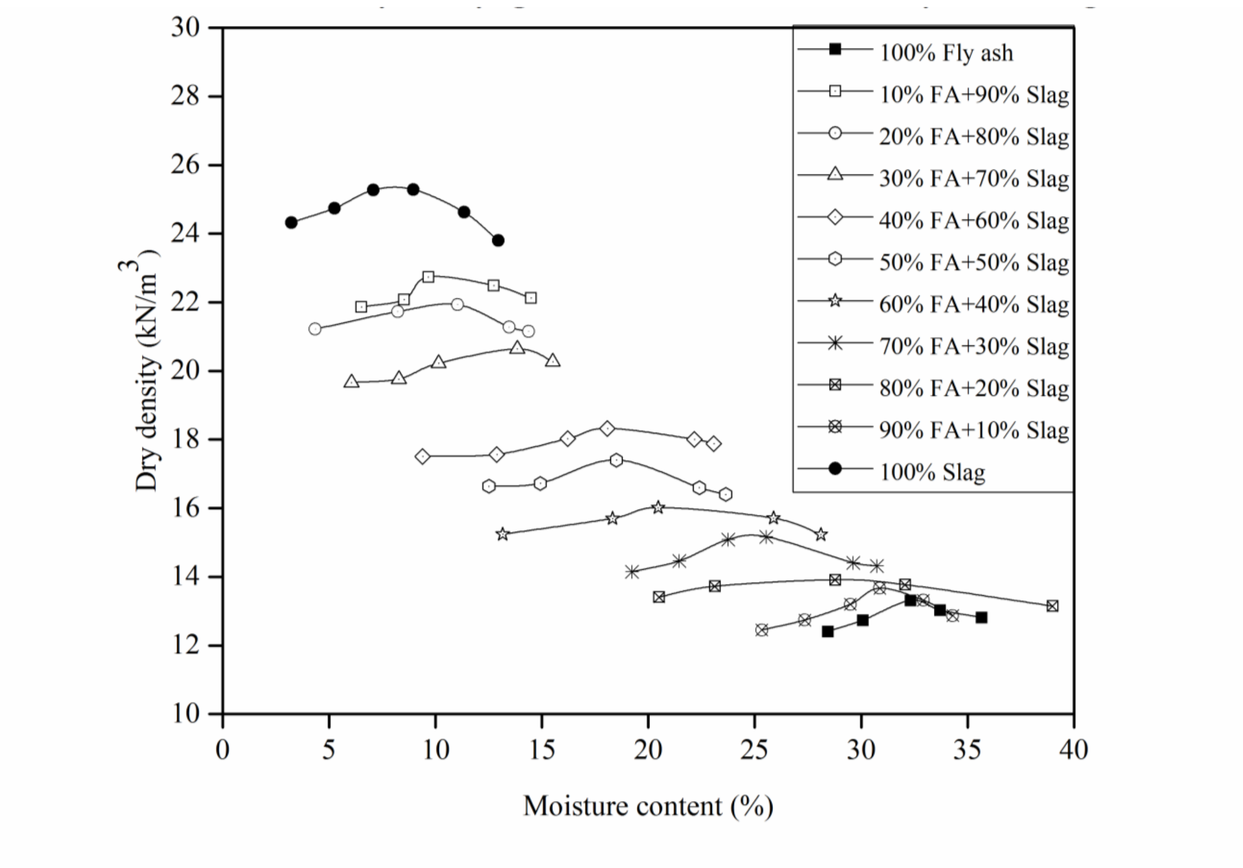

Figure 3.4 Compaction curves for fly ash- slag mixes

3.4.2 Determination of Unconfined Compressive Strength

Unconfined compressive strength tests on various lime stabilized slag- fly ash mixes were performed according to IS:2720 (Part -10),1991. For this test cylindrical specimens were prepared in a split mould with dimension 75 mm (dia.) x 150 mm (high). The stabilized samples were prepared for various slag- fly ash mixes corresponding to their maximum dry density (MDD) and optimum moisture content (OMC) with stabilizing with lime with enhancing percentage of 0%, 2%, 4%, 8%. For each composition two samples were prepared. The lime stabilized samples were kept for 7 and 28 days after coating with wax.

Figure 3.5 View of stabilized samples.

Figure 3.6 Test set up for stabilized samples.

The unconfined compressive test of the stabilized Samples after 0, 7 and 28 days of curing are tabulated in Table 3.4, 3.5, 3.6 respectively.

Table 3.4 Unconfined Compressive Strength (in kN/m^2) of fly ash – blast furnace slag mixes stabilized with lime after 0 days of Curing

% Fly Ash	% Slag	0% Lime	2% Lime	4% Lime	8% Lime
100	0	43.40	57.90	70.49	81.81
80	20	52.87	65.45	79.29	99.43
60	40	61.10	74.26	85.58	108.24
40	60	72.89	88.10	101.95	119.57
20	80	85.89	128.39	168.67	235.38
0	100	9.23	11.33	12.59	80.53

Table 3.5 Unconfined Compressive Strength (in kN/m^2) of fly ash – blast furnace slag mixes stabilized with lime after 7 days of Curing

% Fly Ash	% Slag	0 % Lime	2% Lime	4% Lime	8% Lime
100	0	47.74	399.63	551.60	720.45
80	20	58.26	500.94	562.92	810.69
60	40	67.10	551.60	602.32	855.73

40	60	79.26	607.95	698.02	962.59
20	80	94.71	962.59	1114.57	1283.45
0	100	15.23	112.56	157.60	264.57

Table 3.6 Unconfined Compressive Strength (in kN/m^2) of fly ash – blast furnace slag mixes stabilized with lime after 28 days of Curing

% Fly Ash	% Slag	0 % Lime	2% Lime	4% Lime	8% Lime
100	**0**	**57.32**	**422.93**	**719.60**	**1378.78**
80	**20**	**64.12**	**516.366**	**780.12**	**1538.43**
60	**40**	**73.85**	**785.52**	**1148.20**	**1945.02**
40	**60**	**87.25**	**1131.59**	**1252.58**	**1835.13**
20	**80**	**105.26**	**1163.20**	**1404.91**	**2311.30**
0	**100**	**20.6**	**226.60**	**271.92**	**362.56**

3.4.3 Determination of California Bearing Ratio

In pavement design, bearing ratio is the key parameters, during the evaluation of soil sub grade. California bearing ratio tests have been carried out for various fly ash – slag mixes conducted in accordance with IS:2720 (Part -16),1979. The stabilized samples were prepared for various slag- fly ash mixes corresponding to their maximum dry density (MDD) and optimum moisture content (OMC) with stabilizing with lime with enhancing percentage of 0%, 2%, 4%, 8%. For each composition two samples were prepared. The stabilized samples for soaked and unsoaked conditions were tested and rest samples were kept for 28 days curing under soaked conditions. The CBR test was performed after 28 days of curing. California bearing ratio of the freshly tested stabilized samples for soaked and unsoaked condition is tabulated in Table 3.7. The stabilized samples with increasing percentage of lime i.e. 2%, 4% and 8% after 28 days of curing were tabulated in Table 3.8, 3.9, 3.10 respectively.

Table 3.7 California Bearing Ratio of Samples of fly ash – blast furnace slag mixes stabilized with lime for 0 days (Unsoaked Condition and Soaked Condition)

% Fly Ash	% Slag	Unsoaked CBR (%)	Soaked CBR (%)	Ratio(SOAKED /UNSOAKED
100	0	22.7	6	0.264
80	20	24.6	6.3	0.256
60	40	27.5	6.9	0.251
40	60	29.5	7.5	0.254
20	80	30.8	7.9	0.256
0	100	46	30.7	0.667

Table 3.8 California Bearing Ratio of Samples of fly ash – blast furnace slag mixes stabilized with lime (0%, 2%, 4% and 8% lime) after 28 days (Soaked condition) of Curing.

% Fly Ash	% Slag	CBR value (%)		
		2% Lime	4% Lime	8% Lime
100	0	88.9	143.7	239.5
80	20	141.1	160.8	252.3
60	40	153.9	187.3	260.8
40	60	165.3	203.5	265.1
20	80	198.4	252.3	278.8
0	100	124.3	164.8	145.4

CHAPTER – 4

TEST RESULTS AND DISCUSSIONS

4.TEST RESULTS AND DISCUSSIONS

4.1 INTRODUCTION

Fly ash as discussed above is a by- product of thermal power plant and similarly blast furnace slag is a co product in the process of iron production. In geotechnical constructions a proper understanding of the interaction of various slag- fly ash mixes with lime should be studied. Various laboratory test have been carried out according to Indian Standards such as specific gravity, sieve analysis, hydrometer analysis, heavy compaction test, unconfined compressive strength tests and California bearing ratio test with various slag – fly ash mixes stabilized either lime. The test result are presented and discussed in this chapter.

4.2 INDEX PROPERTIES

4.2.1 Specific Gravity

The specific gravity of fly ash and blast furnace slag was determined according to IS: 2720 (Part- III, Section –I/II) 1980. The specific gravity of fly ash and slag was found to be 2.44 and 3.10 respectively. The specific gravity of fly ash is found to be lower than that of the conventional earth material. Source of coal, degree of pulverization and firing temperature affects the specific gravity of fly ash. Moreover, transportation and deposition of fly ash may lead to mixing with other materials, which influences its specific gravity.

4.2.2 Grain Size Distribution

A particle size distribution curve gives us an idea about the type and the gradation of the soil. Gradation is used to classify soils for engineering and agricultural purposes. Grain size distribution also provides information whether it is well graded, poorly graded, uniformly graded, fine or coarse.

The grain size distribution of fly ash shows that it contains mostly silt size particles with no plasticity. The coefficient of uniformity (C_u) was found out to be 7.755 and the coefficient of curvature (C_c) was found out to be 1.939. The grain size analysis indicates fly ash is well graded. Figure 3.2 shows the grain size distribution of fly ash.

The grain size analysis of blast furnace slag shows that the coefficient of uniformity (Cu) was found out to be 30.63 and the coefficient of curvature (Cc) was found out to be 0.816. The grain size analysis indicates the blast furnace slag is not a well graded one. It is a poorly graded material. Figure 3.1 shows the grain size distribution of blast furnace slag.

4.3 ENGINEERING PROPERTIES

4.3.1 Compaction Characteristics

The compaction characteristics of fly ash – blast furnace slag mixes have been investigated. The OMC and MDD of fly ash – blast furnace slag mixes have been evaluated and presented in Table 3.3. Relationship between dry density and moisture content of various fly ash – blast furnace slag mixes have been shown in Figure 3.4. It is seen that as the slag content increases the MDD increases and the water required to achieve this maximum dry density is reduced. The specific gravity of slag is more than that of fly ash, thus replacement of fly ash by same amount of slag will certainly increase the dry density of the compacted mix.

4.3.1.1 Variation of OMC and MDD with fly ash content

From the figure 4.1 and 4.2 it is seen that with increase in fly ash content, the optimum moisture content (OMC) increase. The increase in optimum moisture content can be explained by the fact that as fly ash is having more specific surface area, hence more fines are available which require more water for lubrication. Hence OMC of the slag- fly ash mixes increases. Further it is seen that with increase in fly ash content in the mixture the MDD value decreases. The reason behind it is that fly ash having low specific gravity may be responsible for this reduced dry density. The following graphs are plotted to show the variation of OMC and MDD with fly ash content.

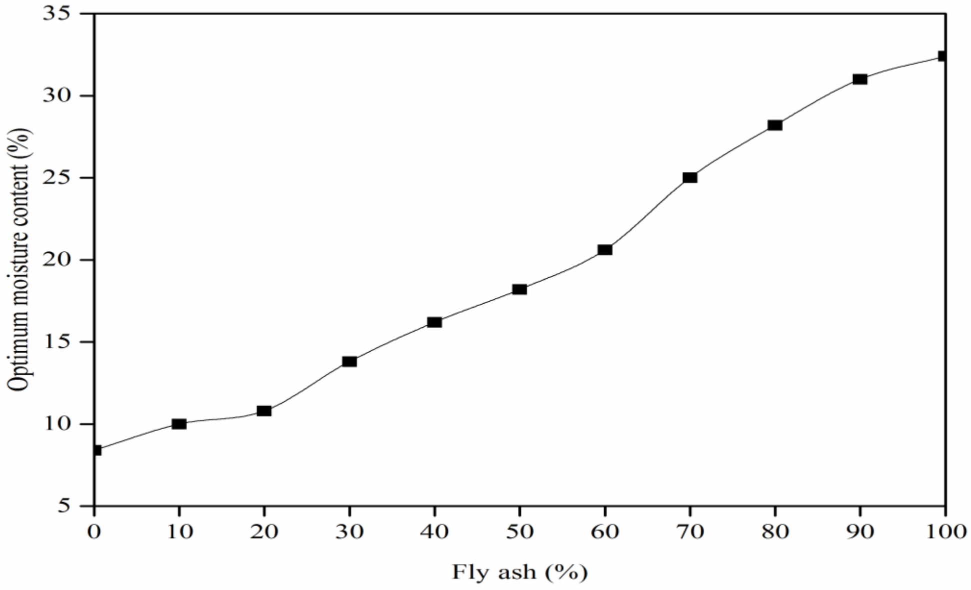

Figure 4.1 Variation of OMC with fly ash content

4.3.1.2 Variation of MDD with fly ash content:

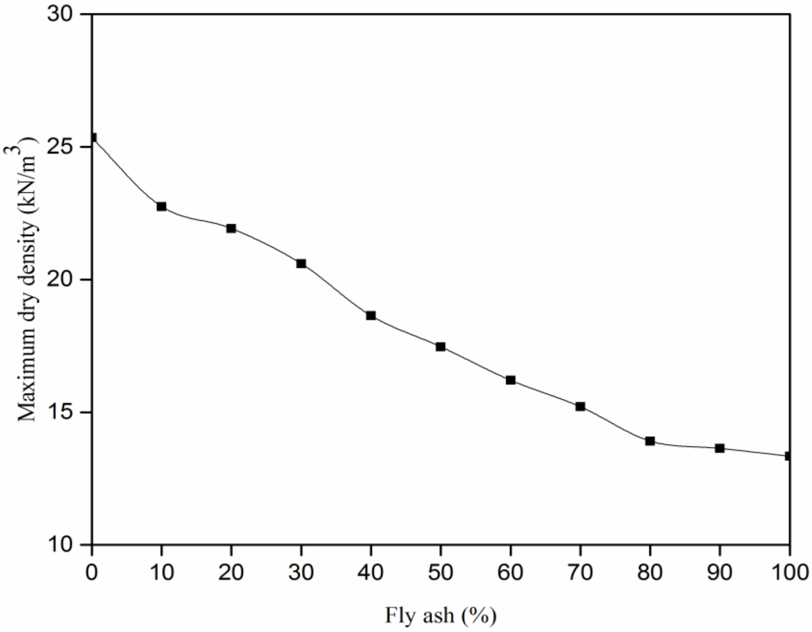

Figure 4.2 Variation of MDD with fly ash content

4.3.1.3 Variation of OMC and MDD with BFS content:

From the Figure 4.3 and 4.4 it is seen that with increase in slag content, the optimum moisture content (OMC) decreases. The decrease in moisture content can be explained by the fact that as slag is having lower specific surface area, hence quite few fines are there, which require less water for lubrication. Hence OMC of the slag- fly ash mixes decreases whereas the MDD value is found to be increased with increase in slag content. The reason behind it is that slag having high specific gravity may be responsible for this increase in MDD value of the mix. The following graphs are plotted to show the variation of OMC and MDD with slag content.

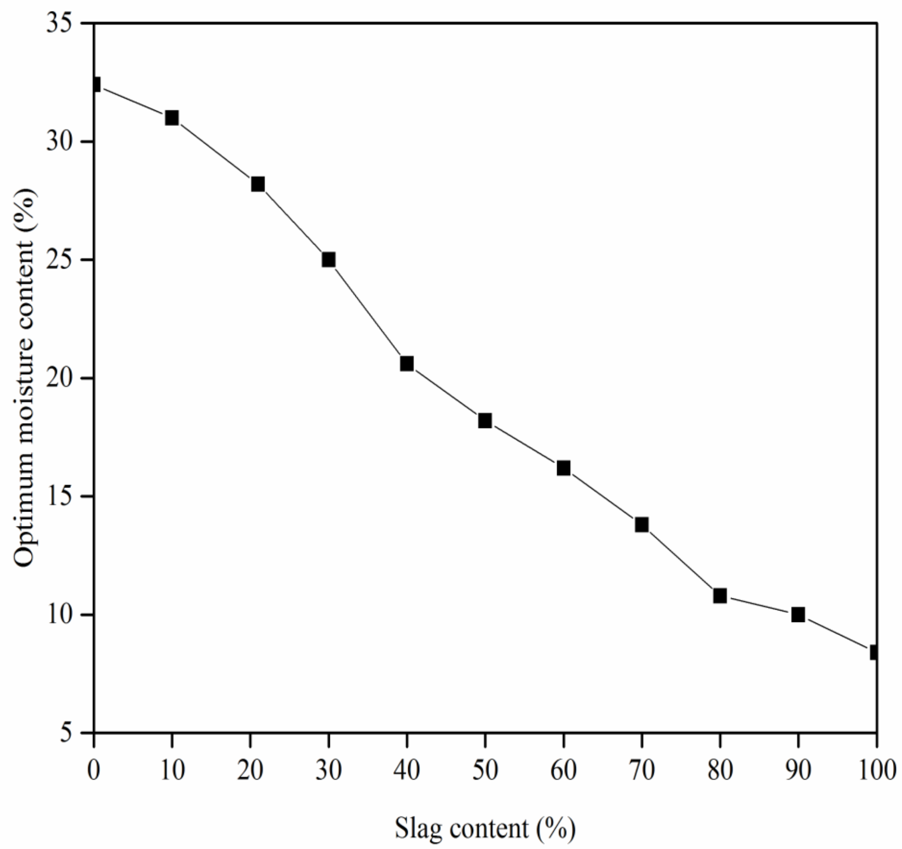

Figure 4.3 Variation of OMC with Slag content

4.3.1.4 Variation of MDD with BFS content:

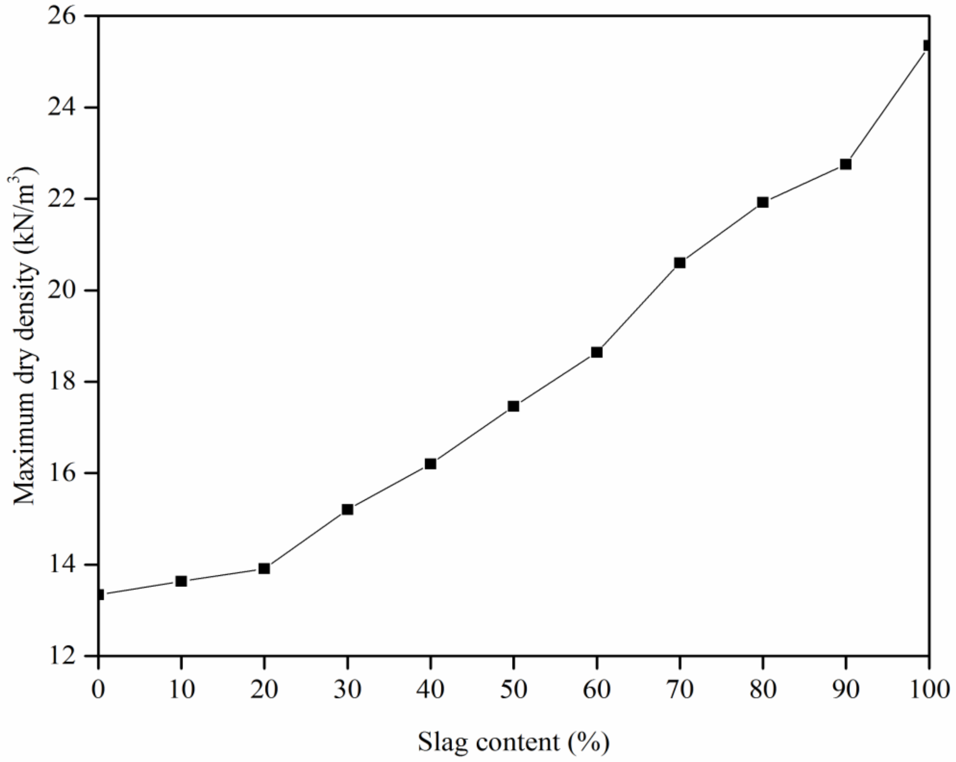

Figure 4.4 Variation of MDD with slag content

4.3.2 Unconfined Compressive Strength

4.3.2.1 Effect of Lime

With increase in lime content, the unconfined compressive strength values increases. At 0 days, the maximum UCS value comes to be 235.38 kN/m^2 at 8 % lime content for 80% slag of the slag – fly ash mixes. Similarly, at 7 and 28 days, the maximum UCS value comes to be 1283.45 kN/m^2 and 2311.30 kN/m^2 at 8 % lime content for 80% slag of the slag – fly ash mixes. The strength of fly ash- slag mixes did not significantly increase on the very first day of testing. Considerable increase in strength was noticed on 7 and 28 days of curing, which can be attributed to the fact that as the percentage of slag increases, both material added sufficient lime and silica for the pozolanic reaction and thereby attending considerable strength. The mixture containing 80% slag of the slag – fly ash mixes showed higher strength after 28 days of curing as compared to other mixes. This may be due to formation of compact structure with coarse grain slag particles acting as skeleton whereas fly ash particles act as void filler in the skeletal structure. A too high percentage of slag leaves behind a porous structure which might have reduced the strength whereas at higher fly ash content the grain to grain contact between the coarse slag particles gets lost thereby reducing the mechanical strength. Further it is noticed that with increase in curing period the strength increases continuously. The formation of cementitious compounds like calcium silicate hydrate (CSH) depends mainly on curing period, hence higher strength is obtained at 28 days of curing. Following graphs are plotted to show the Variation of UCS value with lime content.

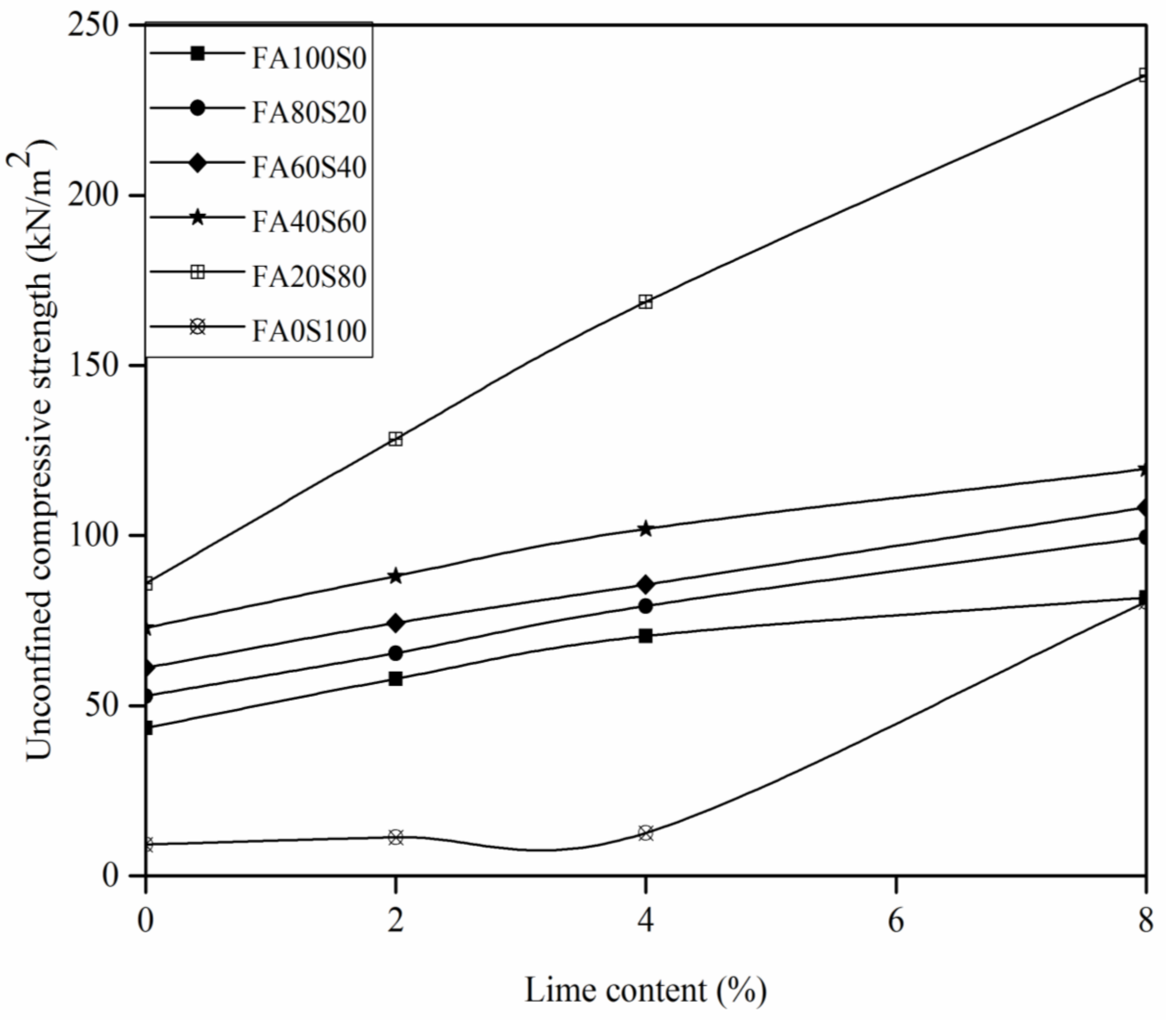

Figure 4.5 Variation of UCS with Lime Content at 0 Days

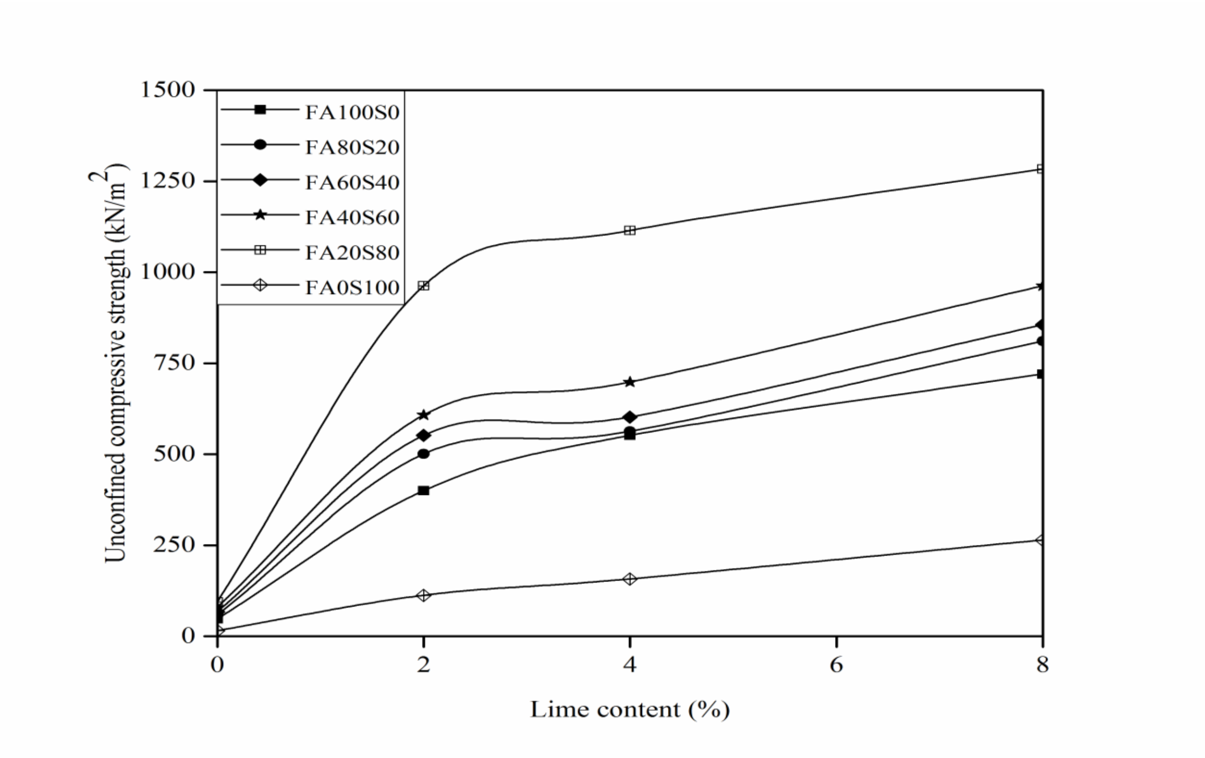

Figure 4.6 Variation of UCS with Lime Content at 7 Days

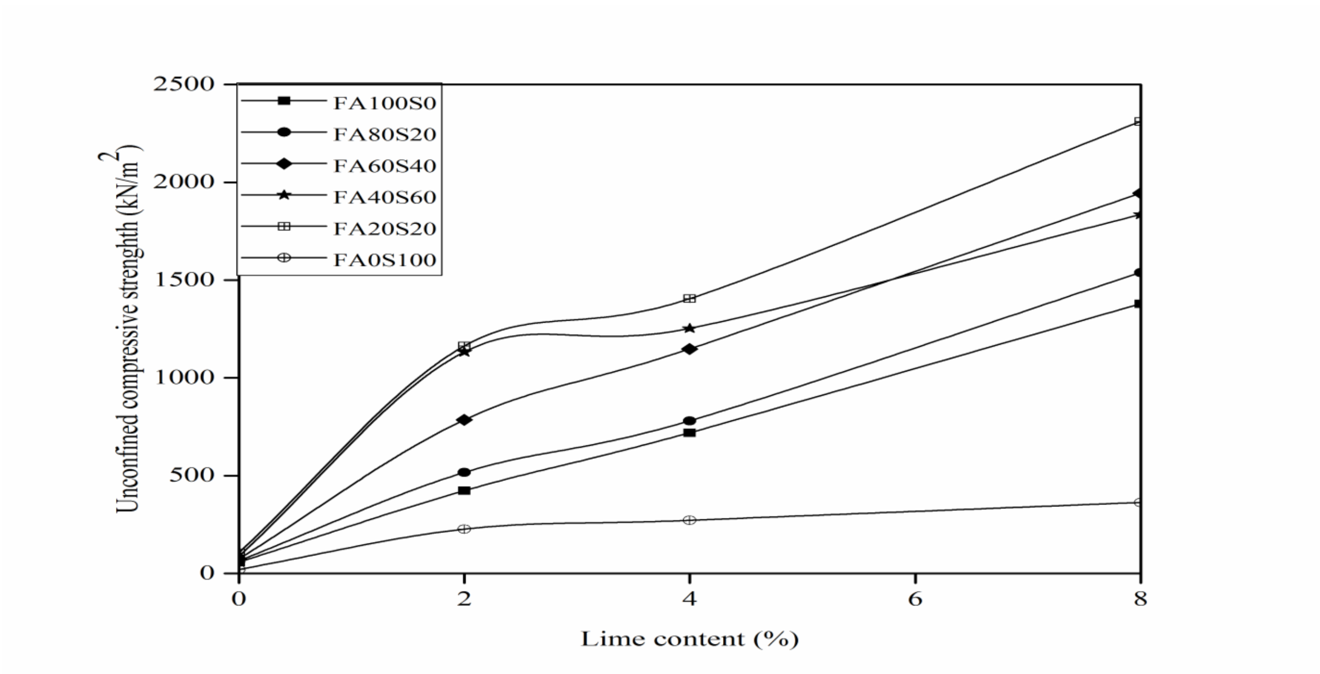

Figure 4.7 Variation of UCS with Lime Content at 28 Days

4.3.2.2 Effect of curing period

The strength of stabilized fly ash –slag mixes increases with curing time. At 0% lime, maximum UCS values are around 105.26 kN/m^2 at 28 days of curing for 80% slag of the slag- fly ash mixes. Similarly, at 2%, 4%, 8% lime, maximum UCS values is around 1163.20 kN/m^2 ,1404.91 kN/m^2 and 2311.30 kN/m^2 at 28 days of curing for 80% slag of the slag- fly ash mixes. Slag contains appreciable amount of unreacted lime, however this latent hydration property of the slag is to be activated by an alkali. So extra amount of lime is used to activate the slag and initiates the pozzolanic reaction. As cementitious reactions are slow in slag, stabilizing agent is required. In the presence of lime, the reaction is accelerated, forming cementitious compounds like CSHs providing strength. The CSH gel is responsible for binding the materials in the slag – fly ash mixes together and increasing strength of the mixture. A similar trend was observed with addition of 4 and 8% lime. The quantity of gel formation increased with increase in lime content and hence particles are more effectively bound. Following graphs are plotted to show the variation of UCS value with curing period.

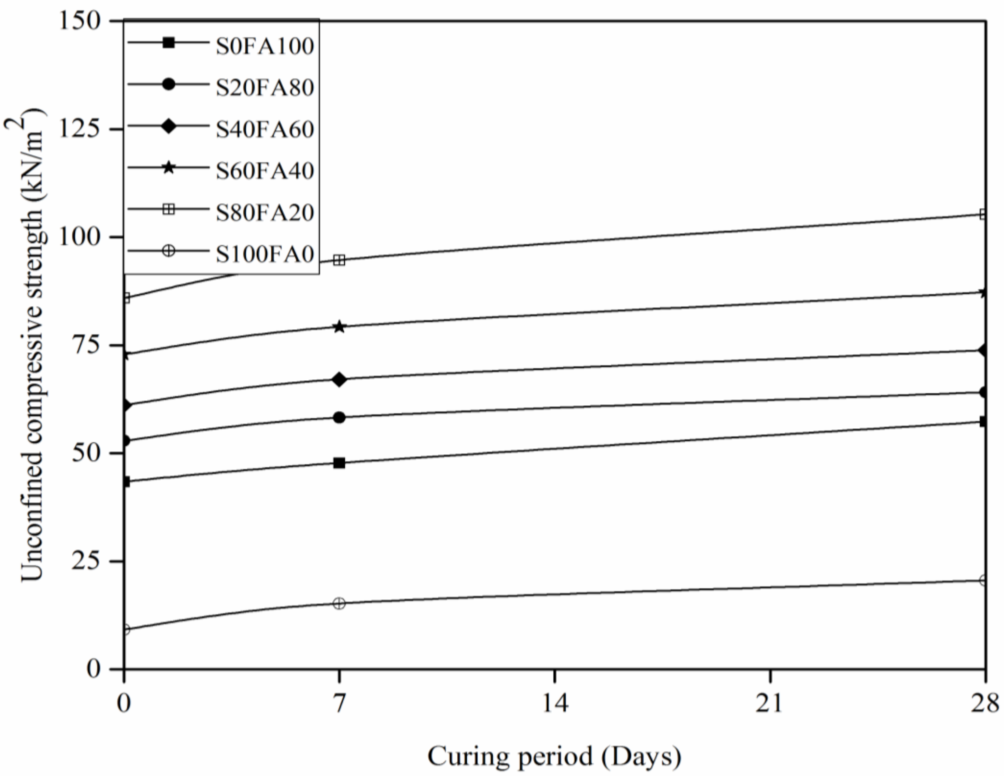

Figure 4.8 Variation of UCS with curing period with 0 % Lime

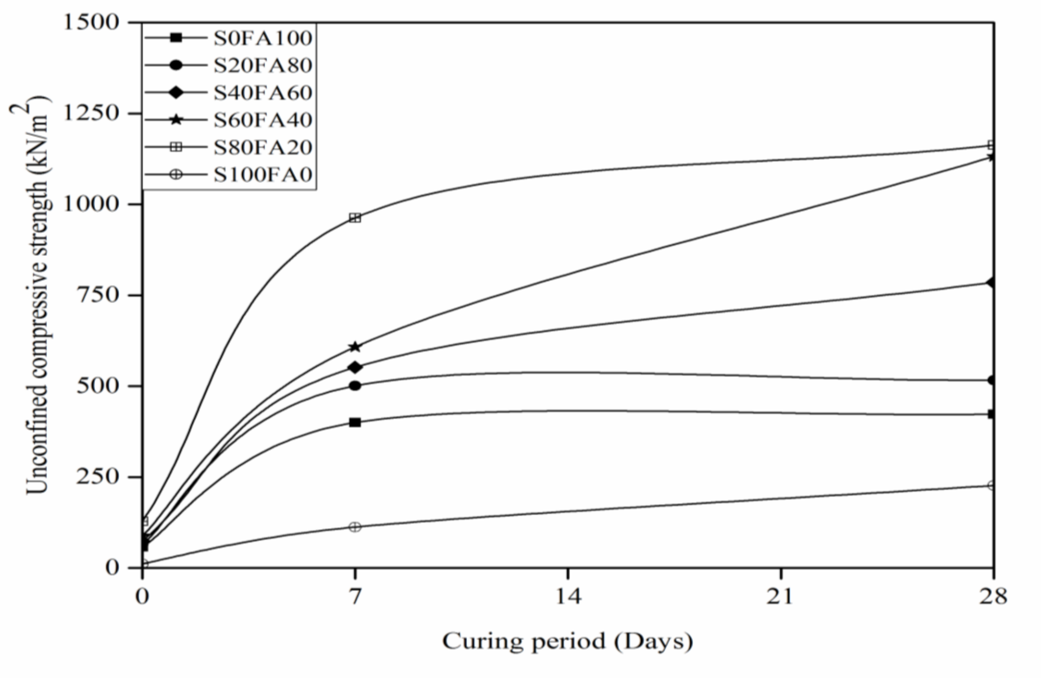

Figure 4.9 Variation of UCS with curing period with 2 % Lime

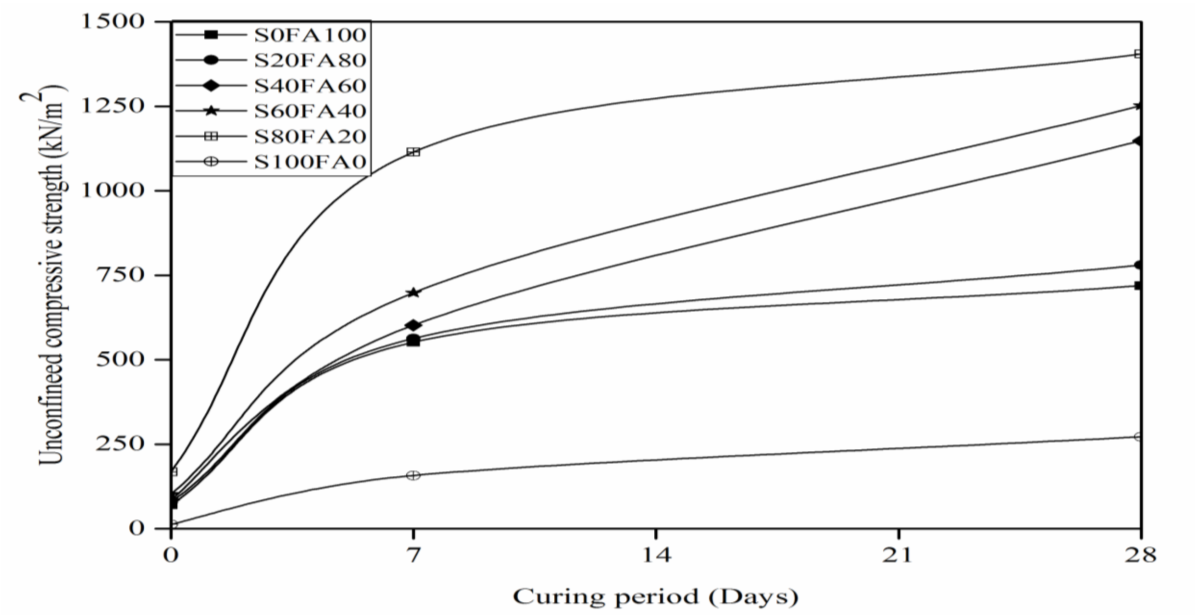

Figure 4.10 Variation of UCS with curing period with 4 % Lime

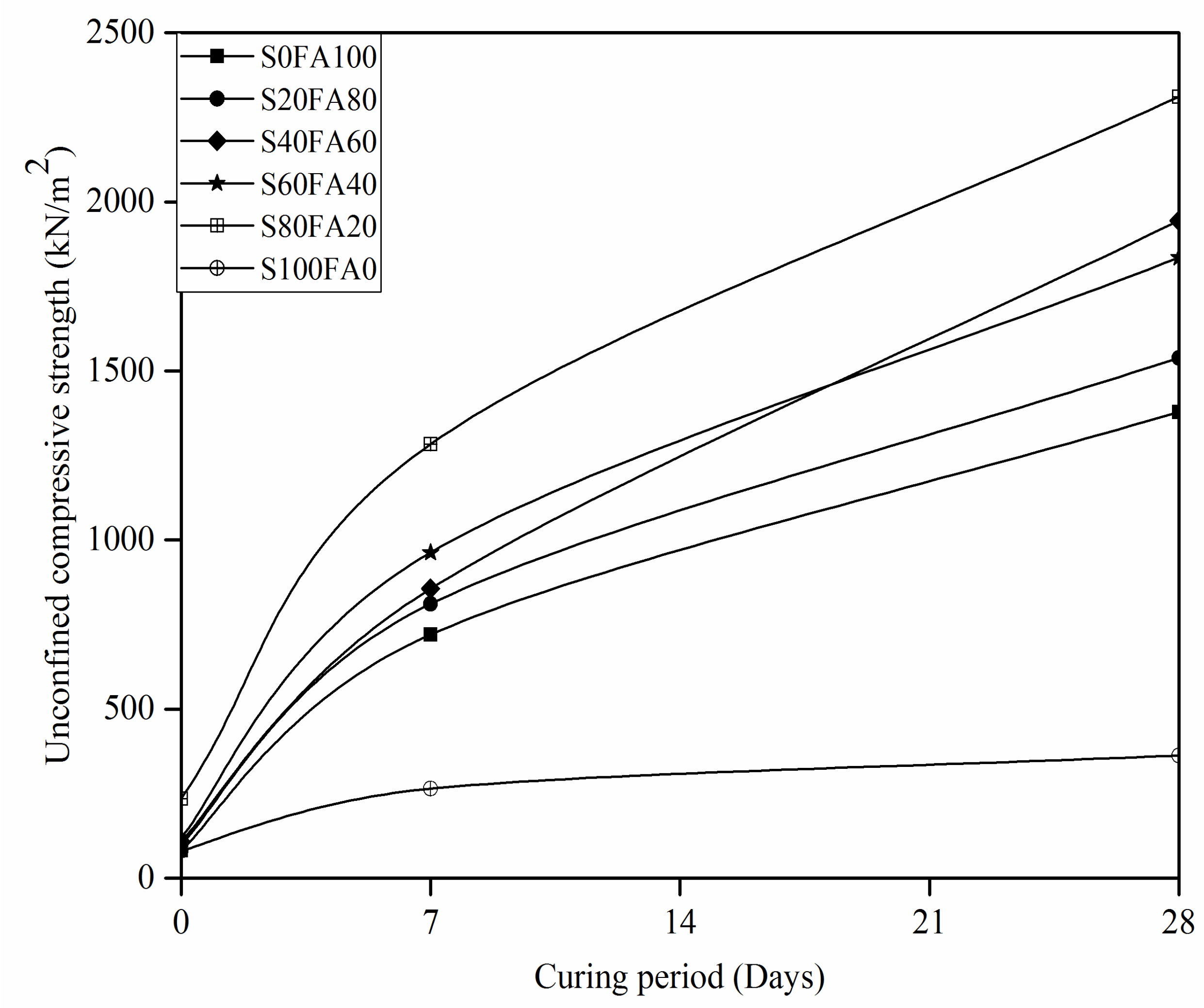

Figure 4.11 Variation of UCS with curing period with 8% Lime

4.3.2.3 Effect of fly ash/slag content

The maximum UCS value is obtained for 80% slag of the slag- fly ash mixes. The addition of slag to fly ash –slag mixes increases the strength of lime stabilized mixes which is maximum at 8 % lime. This increase in strength may be due to the fact that slag contains some percentage of unreacted calcium oxide, which reacts with silica and alumina producing hard masses. Moreover, the addition of slag to fly ash makes the mix well graded thus increasing the compacted density and hence mechanical strength of the compacted mixture also increases. The addition of slag to fly ash mixes accelerates pozzolanic reaction. Following graphs are plotted to show the variation of UCS value with fly ash content.

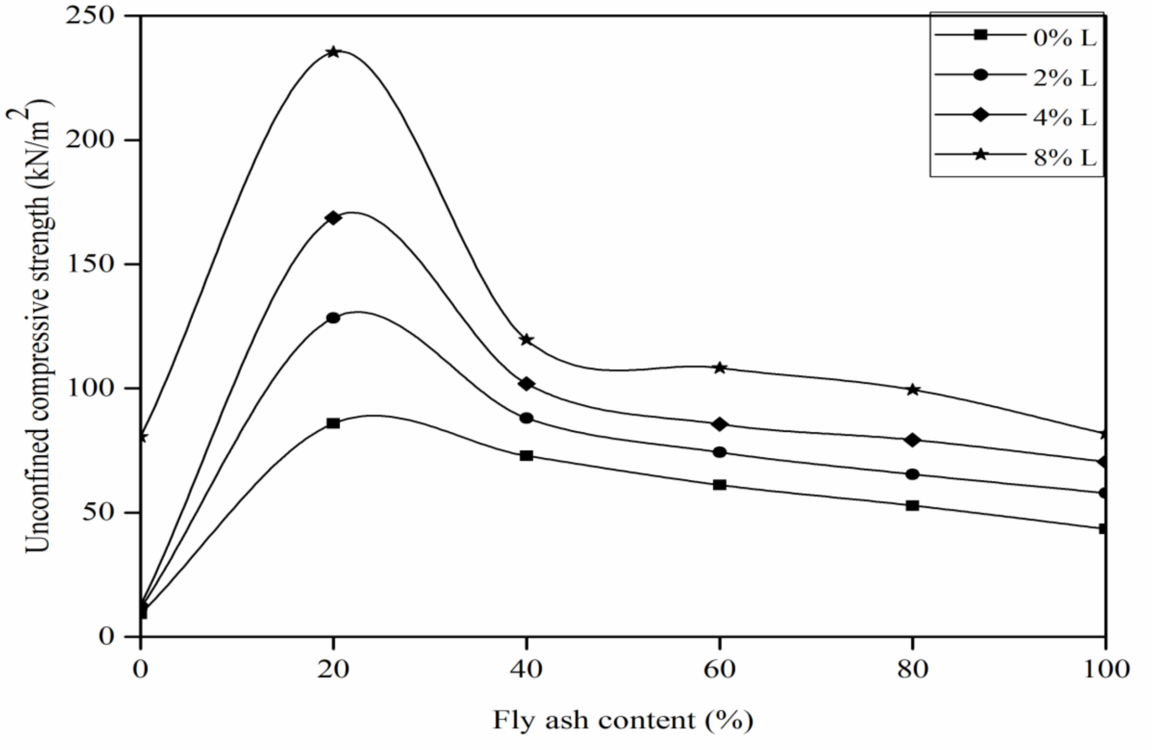

Figure 4.12 Variation of UCS with fly ash content at 0 days

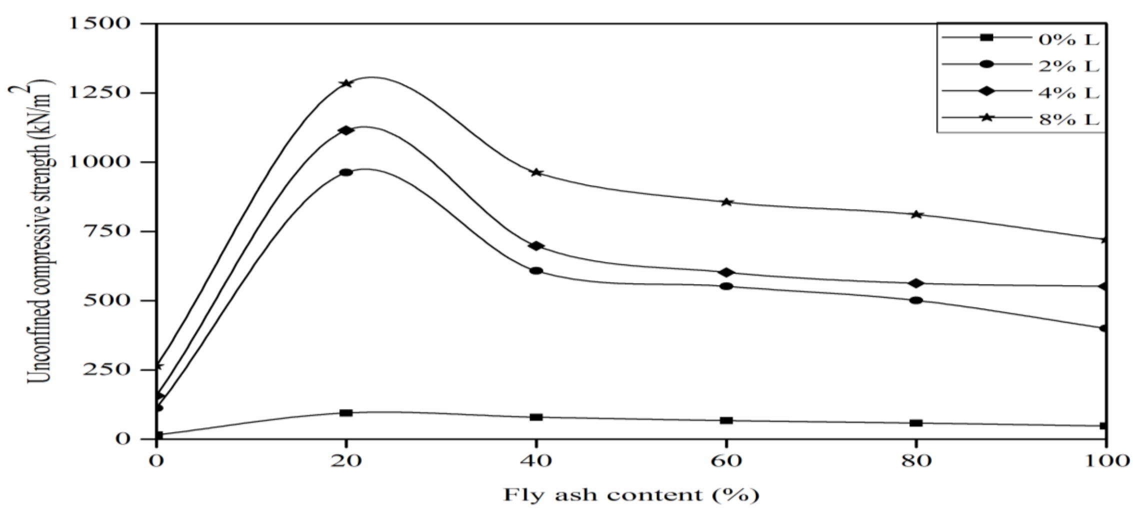

Figure 4.13 Variation of UCS with fly ash content at 7 days

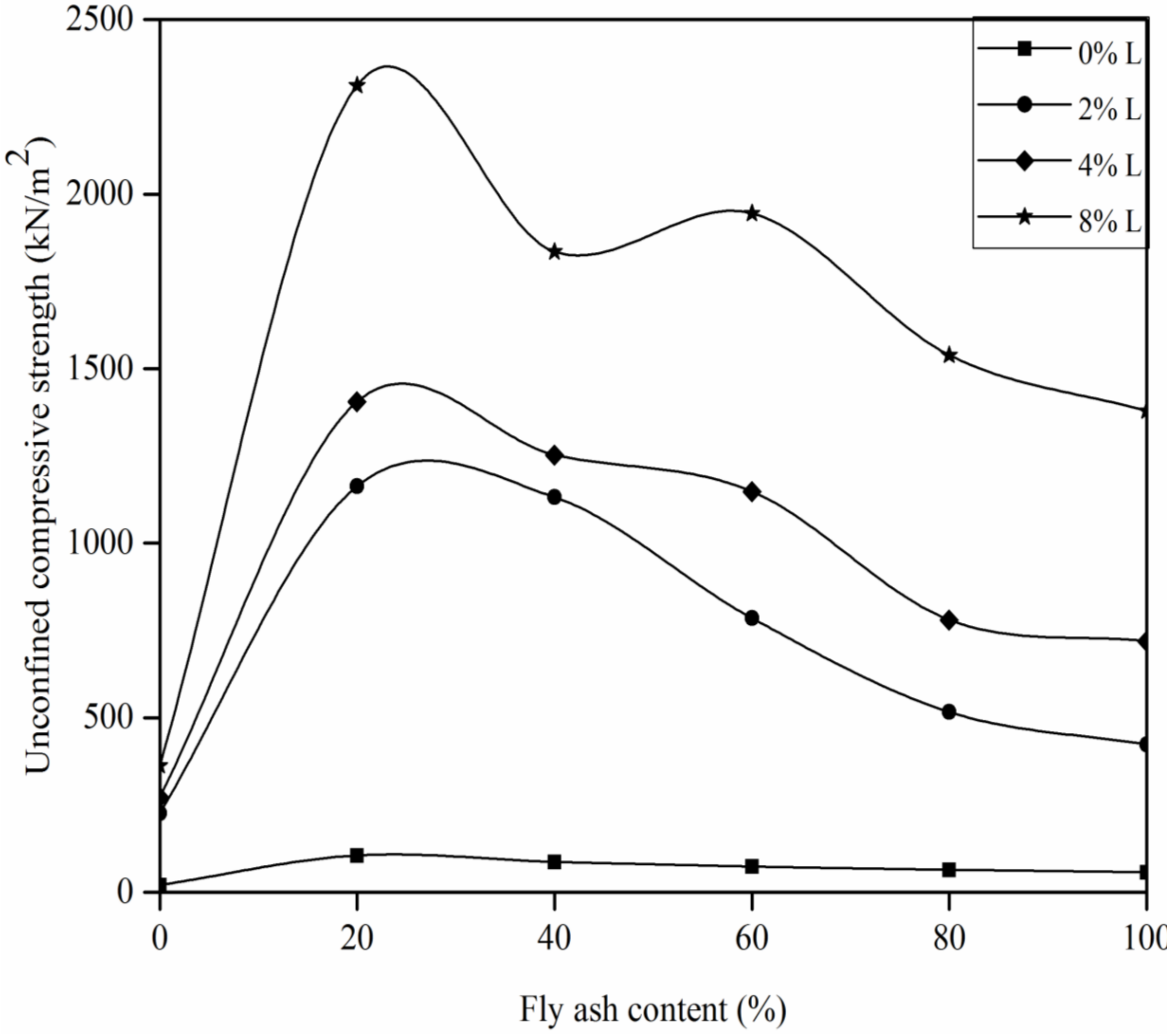

Figure 4.14 Variation of UCS with fly ash content at 28 days

4.3.3 California Bearing Ratio

4.3.3.1 Effect of Lime

With increase in Lime content, the CBR values also increases, maximum CBR value was reported as 278.8 % at 8 % lime having 80% slag in the slag –fly ash mixes. However at maximum slag content the CBR value shows a lesser value. The increase in CBR value after addition of lime can be attributed to the fact that formation of various cementing agents due to pozzolanic reaction between reactive silica and alumina present in the slag and lime. Following graphs are plotted to show the variation of CBR value with Lime content.

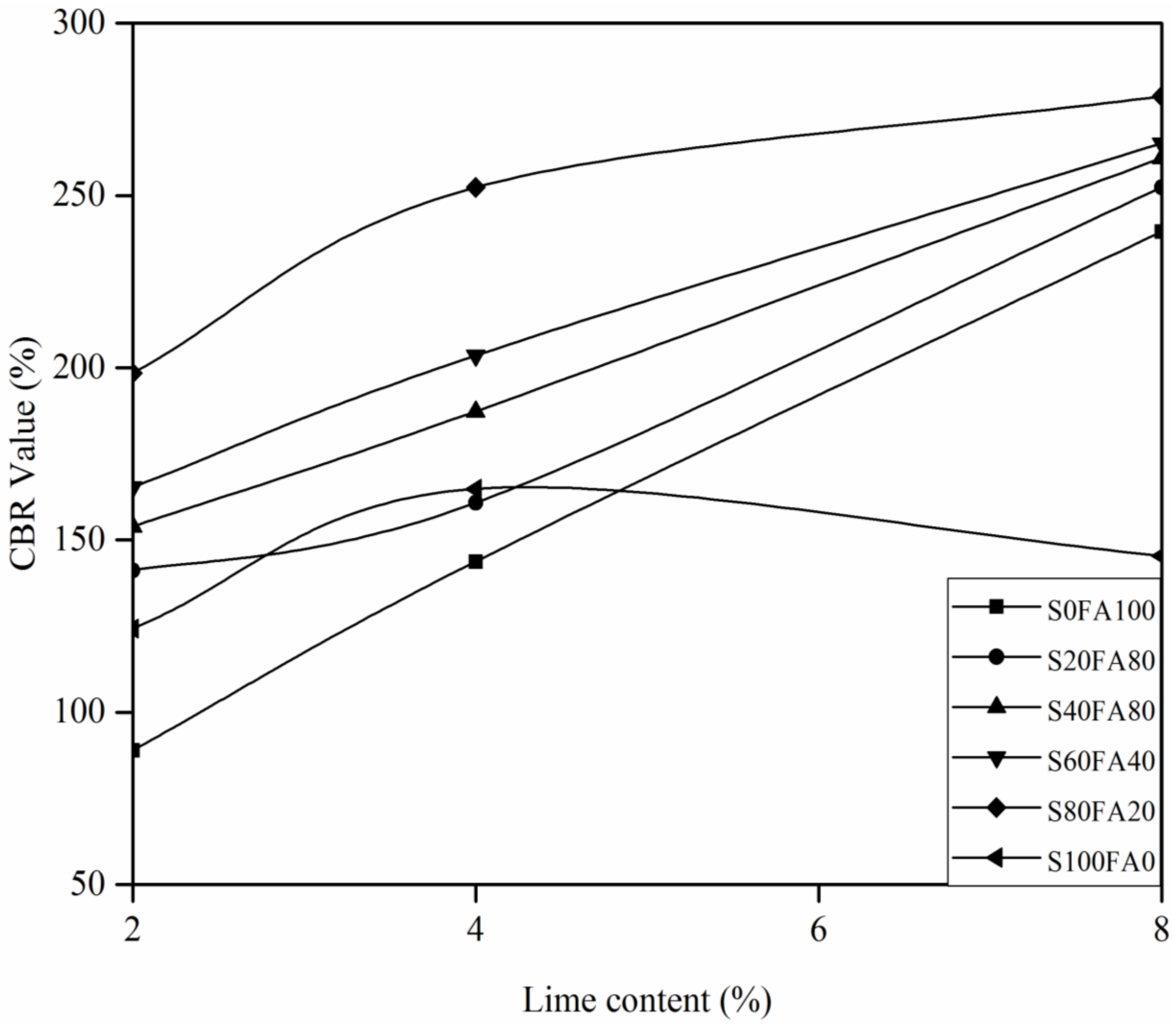

Figure 4.15 Variation of CBR with Lime content at 28 days

4.3.3.2 Effect of Fly ash/slag content

With increase in slag content, the CBR value follows a increasing trend. The increase of CBR values can be attributed to increase in mechanical strength of fly ash –slag mixes. Moreover, the free calcium oxide present in slag helps in pozzolanic reaction which imparts higher strength. Hence, addition of slag to fly ash- slag mixes attains higher CBR values. However CBR values attain a higher value at 80% slag of the slag-fly ash mixes at 28 days of curing. The mechanical strength of the mixture largely depend on the amount of chemical added, specific surface area of the material, crushing strength of constituent particles, gradation of the mix and to some extent the particle shape. In this present investigation, a mixture containing (80% slag +20% Fly ash) gives the highest strength. This indicates that at this mixed proportion, the resulting void ratio is the minimum. Thus a more dense mass is formed which renders higher compressive strength. Following graphs are plotted to show the Variation of CBR value with fly ash content.

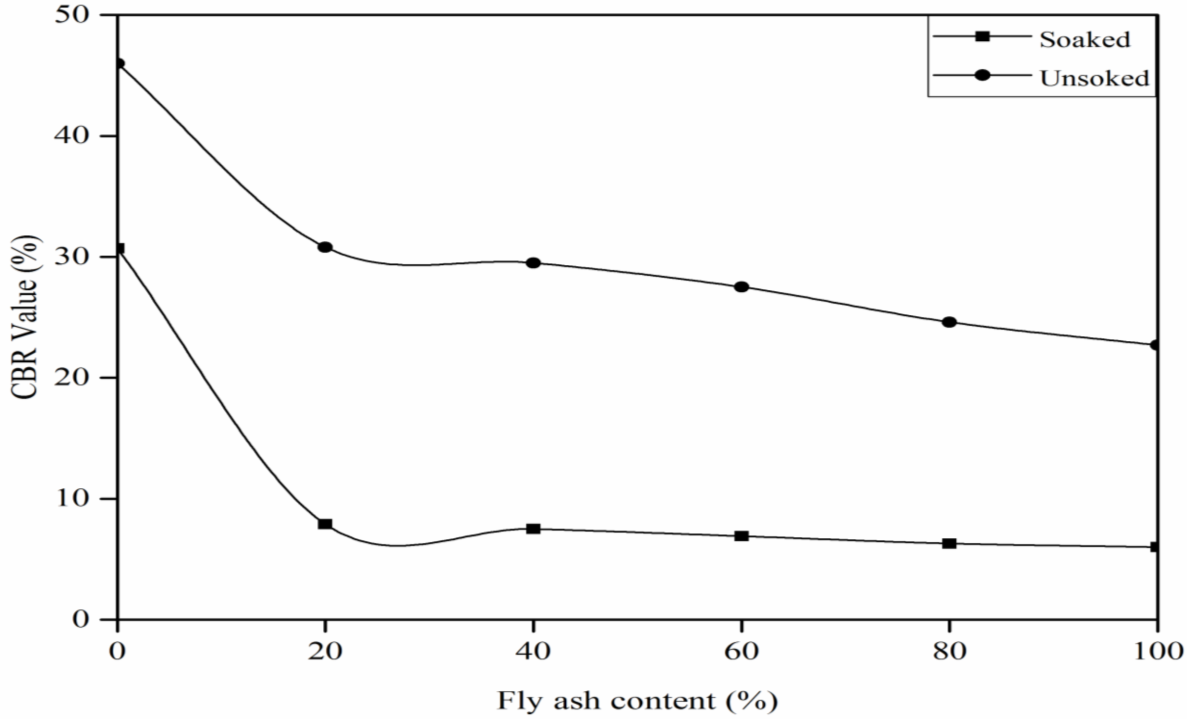

Figure 4.16 Variation of CBR with fly ash content at 0 days

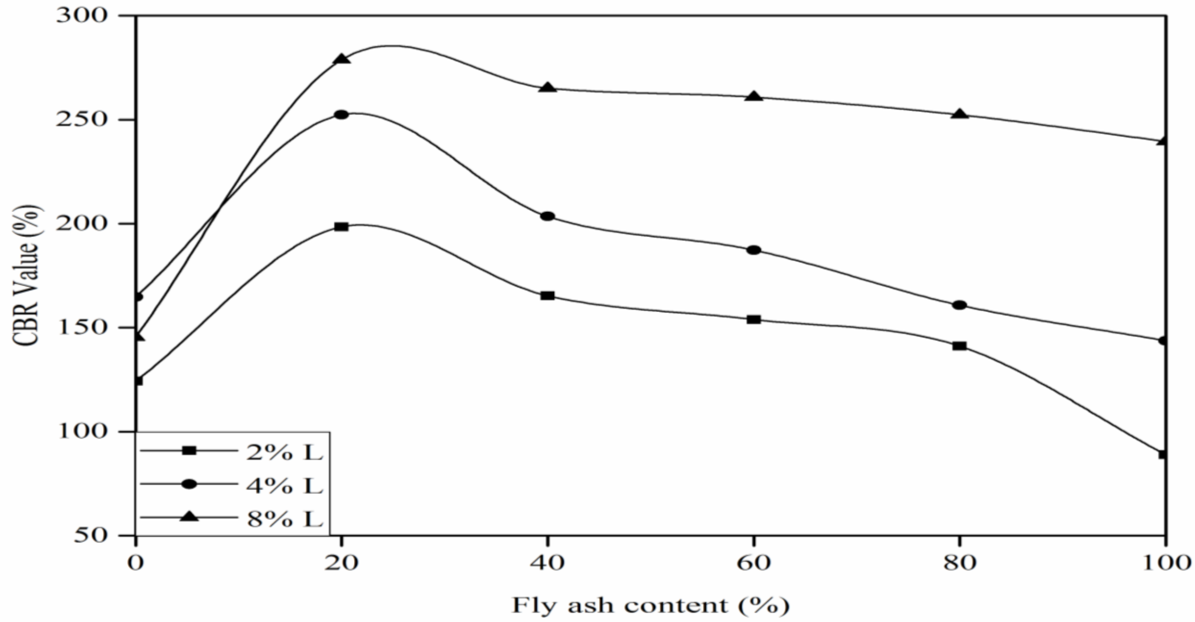

Figure 4.17 Variation of CBR with fly ash content at 28 days

4.4 Evaluation of lime stabilized fly ash – slag mixes as a highway construction material

According to the IRC: 37- 1984 for cumulative traffic up to 2 million standard axle (MSA), the CBR value for sub-base course should be between 20-30 % , for base course it lies between 80-100% and for sub grade course , the CBR value should not be less than 25%. The CBR value of unstabilized fly ash – slag mixes ranges from 6 -30% , which will fail to satisfy the CBR requirement of different pavement layers. And the combination of fly ash and slag alone will also not be able to cope to the CBR requirement. Hence the CBR test of lime stabilized slag- fly ash mixes were conducted. It is seen that CBR value ranges from 6-278.8% for fly ash- slag mixes stabilized with lime. But depending upon the traffic load and pavement layer, particular fly ash- slag mixes stabilized with lime is designed which can be successfully utilized in base and sub- base courses of highway pavement. The desired lime stabilized fly ash- slag mix will be a promising material in reducing the use of natural soil in addition to mitigate the disposal problems of industrial solid wastes in a greater way.

CHAPTER 5

CONCLUSION

5. CONCLUSION

Experiments are carried out to investigate the geo-engineering properties of fly ash- slag mixes stabilized with lime. The geo engineering properties are investigated by the effect of lime on fly ash- slag mixes. Based on the experimental finding the major conclusions drawn from this study are as follows.

- Fly ash is mostly well graded material within its size range having specific gravity lower than that of slag. The low specific gravity of fly ash is because of the presence of cenospheres.
- The addition of blast furnace slag to fly ash- slag mixes increases the MDD and decreases its OMC value linearly. This is due to the fact that fly ash having more surface area and more fines are present , which require more water for lubrication and thus OMC values keeps on increasing with the increase in fly ash content.
- The UCS value of the fly ash- slag mixes increases with the addition of slag. The mix with 80% slag shows higher value as compared to 100% slag. Moreover the UCS value is maximum for 8% lime in the fly ash - slag mixes subjected to 28 days of curing. This is due to fact that in the presence of lime, the reaction is accelerated forming CSH gel responsible for strength in the mixture.
- The maximum strength observed at 0 days curing is about 235.38 kN/m^2 at a lime content of 8%. After 28 days of curing for the same slag – fly ash mix the maximum UCS value is around 10 times higher than 0 days curing and value is around 2311.30 kN/m^2.
- The CBR value of the fly ash- slag mixes increase with the addition of slag. As that of UCS, similar pattern were observed for CBR values, with 80 % slag the CBR values reported were higher having lime content 8% subjected to 28 days of curing. The increase of CBR values can be attributed to increase in mechanical strength of fly ash –slag mixes.
- The desired lime stabilized fly ash- slag mix will be a promising material in reducing the use of natural soil in addition to mitigate the disposal problems of industrial solid wastes in a greater way and can be successfully utilized in base and sub- base courses of highway pavement.

CHAPTER 6

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